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AVAILABILITY OF THE CAÑONS OF THE COLORADO RIVER OF THE WEST FOR RAILWAY PURPOSES.

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WITH DISCUSSION.

Before entering upon the subject of this paper, a short explanation is necessary, on account of the apparent tardiness in its presentation. It was the intention of the writer, immediately on the completion of the survey down the Colorado River, in May, 1890, to prepare an account of that work and some of its peculiar engineering features, to be read before the Society; but pressing engagements, making a report for the railway company, etc., prevented its preparation that summer. At the Cresson convention, in June, 1890, the Society did the writer the honor to spend the greater part of one evening looking at some one hundred and fifty stereopticon views of the cañons through which the survey passed, while he gave a running talk and description of some of the ex-

periences of the journey, and in answer to many questions attempted to explain the engineering difficulties of the route.

Although the subject has thus been presented before the Society, it seems proper to put in a more permanent form a record of the methods employed and the results obtained in an undertaking which has at least one attractive feature, that of novelty. This novelty is twofold: the very boldness of the conception of constructing a railway at the bottom of the supposed impassable cañons through which this great water course runs, and on account of the numerous rapids, falls and cataracts in the river, the dangerous and exciting work necessary while navigating it, in order to make what would have been otherwise a simple exploratory survey.

It would be entirely out of place in such a paper as this, to enter into a description of the many adventures of the expedition while making the survey, its perils by land and by water; or to picture the wonderful and beautiful scenery of those remarkable cañons. However, although it shall be confined to the engineering problems encountered, and to such a description of the country as may relate to a railway route, yet it will be necessary, in order to make clear the nature of the work and the methods employed, to refer to some incidents of the journey that were not technically engineering experiences.

The question of a low grade railway line from the western base of the Rocky Mountains to tide water on the Pacific Ocean, by way of the Colorado River of the West, is not a new one. It has been discussed by engineers for twenty years at least, ever since the first explorations of the great cañons of that river by Major J. W. Powell in 1869. This exploration by Major Powell was undoubtedly the first journey ever made through these cañons. Some wild stories are told of two men having gone through the Grand Cañon on a raft of small cottonwood logs. This story was first published in General Palmer's report on the Pacific Railway Surveys,* and afterward republished with many embellishments by the author, and illustrated with some outlandish pictures, in Bell's "New Tracks in North America."†

While no records have yet been found that show any earlier exploration of the Colorado River, by passing along its waters and through its

* "Report of Surveys Across the Continent," 1868, General William J. Palmer.

† "New Tracks in North America," William A. Bell, London, 1870.

cañons, than that of Major Powell in 1869, some discoveries seem to point to an attempt at least, made more than thirty-three years before.

While making the survey through the lower part of Cataract Cañon the writer discovered an inscription, or rather a name and date, thus:

"1836

D. Julien."

This in itself would not appear very wonderful; but when taken together with the following facts is significant. This inscription was cut with a tool resembling a dull center punch. It is upon the wall of the cañon under an overhanging cliff, and at such a height and in such a position—where the water fills, and undoubtedly at that time, filled the whole gorge from wall to wall—that it could only have been cut from a boat (or other float), and at quite a high stage of water. The point is on a level, smooth stretch of the river, but above some heavy and narrow rapids, on account of which it would have been practically impossible to reach this stretch of water from below. The inscription is considered entirely genuine, both from its position, as well as the style and shape of the letters and figures used. Hence the writer is led to believe that this was cut by a party descending the river.

A very slight investigation of this shows that about the time of the date given upon the wall of the cañon, a party of French voyageurs, traveling in the Northwest, divided into two parties, one starting to explore in the Southwest. It has as yet been impossible to push this investigation any farther, though it is believed that some records of these voyageurs still exist; but whether these records will show the previous history of the man who cut the name and date in the cañon or not, it is extremely doubtful if anything farther can be learned of the results of his journey, or how much farther down the river he went before he was swallowed up in its mighty cataracts.

For the purposes of a convenient record it will perhaps not be out of place to give a short account of the earliest examinations of the lower or valley division of this notable river.

The Gulf of California and the mouth of the Colorado were first discovered, as far as we have any account, by the naval division of the expedition of Francisco Vasquez de Coronado, in the spring of 1540. On the 26th of August, 1540, two Spanish shallops, under command of Fernando Alarcon, started up the river. They traveled fifteen and a half days, and then turned back. On the 14th of September of the

same year Alarcon again started up the river, and continued for a distance of 290 miles, when he returned to the mouth.

It has generally been supposed that the first attempt to navigate the lower Colorado with steamboats of any size was made by Lieutenant Ives in 1858. By some recent investigations it is found that this is not the case. Captain George A. Johnson, who now resides at San Diego, Cal., first went to the mouth of the Colorado in 1851. Soon after that he built at that point three steamboats, and as early as April, 1852, went up the river by steamboat as far as Fort Yuma, at the mouth of the Gila River.

Captain Johnson continued to navigate that portion of the river a distance of nearly 150 miles, carrying supplies to the Government troops and settlers till the fall of 1857. In December of that year Captain Johnson made his first trip to any distance above Fort Yuma. This journey up the Colorado was made in the steamboat *General Jessup*, a boat 108 feet in length, of 28 feet beam, and drawing 2 feet 6 inches of water. With a military escort under Lieutenant James White, of the 3d U. S. Artillery, they started from Fort Yuma in December, 1857, and steamed up the river to El Dorado Cañon, about 68 miles below the mouth of the Rio Virgin. Captain Johnson was engaged in this expedition between three and four months, and while coming down the river met Lieutenant Ives and his Government party some distance above Fort Yuma. Lieutenant Ives reached the mouth of the Colorado the 29th day of November, 1857, and started up the river with his little steamboat, *The Explorer*, on the 21st of December, 1857. After passing Captain Johnson on the river he proceeded up to El Dorado Cañon, where the *General Jessup* had been before him, and for some few miles beyond into the Black Cañon.

A very interesting account of this expedition may be found in Lieutenant Ives' report published by the Government; * but it is rather remarkable that he does not mention Captain Johnson's boat, which was large enough to have stowed away out of sight Lieutenant Ives' little *Explorer*. The river is navigable for steamboats drawing from 3 to 4 feet for about 575 miles to the mouth of the Rio Virgin. Its navigation has some peculiarities. One trip of the steamboat *Gila*, a boat 180 feet in length, required nearly four days from El Dorado to the

* Report of Lieutenant Joseph C. Ives, 1857–8, Senate Ex. Doc., 30th Congress, 1st Session.

Rio Virgin; but in returning with a load of 80 tons of salt the same distance of 68 miles was made in three hours and ten minutes.

Since 1869 many attempts have been made to descend the Colorado in boats, but without success until the expedition of which the writer of this paper was in charge, beginning at Green River Station, Utah, May 25th, 1889, and finally completed at tide-water at the head of the Gulf of California, in the Mexican State of Sonora, on April 26th, 1890. During the years 1870–73, the United States Government made a careful and extensive geological survey of the country through which the Colorado flows. The results of this work are found in the very able and extensive reports of Captain C. E. Dutton to the Director of the Geological Survey.

In order to clearly understand the engineering features of this section of our country for a railway route, it will be necessary, and it is hoped both profitable and interesting, to give a short account of the geological creation of this whole area, and also some history of the formation of this most remarkable and peculiar river course.

By referring to a map of the western part of the United States (Plate XXVI) it will be seen that the Colorado River of the West is formed by the junction of the Grand and the Green rivers. The Green River rises in the Wind River Mountains in the northwestern part of Wyoming, and flows in a southerly direction through Wyoming and Utah. The Grand River rises in the northern central part of Colorado; its head waters being the Grand Lake, which is situated at the western base of the Rocky Mountains, close up under the Continental Divide, and about 42 miles west and 33 miles north of the City of Denver. Flowing in a generally southwestern course, it forms a junction with the Green River in the western part of the Territory of Utah. The waters of these two form the Colorado. This river flows in a generally southwestern course to the mouth of the Colorado Chiquito, in the Territory of Arizona. Thence its general course is west to the mouth of the Las Vegas Wash, about 30 miles below the mouth of the Rio Virgin, in the State of Nevada; and thence its course is almost due south, forming as it does the boundary line between the Territory of Arizona on the east, and the States of Nevada and California on the west, until it empties into the Gulf of California, in the Mexican State of Sonora. Taking the Green as the main branch, this river course is something over two thou-

sand miles long. The distance from Grand Junction to the Gulf is in round numbers twelve hundred miles.

For the purposes of railway examination the Colorado River may be divided into two general divisions:

First.—That from the mouth of the river up to the mouth of the Grand Cañon, a point about 38 miles east of the Rio Virgin, and near the eastern line of the State of Nevada. This may be called the Lower or Valley Division.

Second.—That from the mouth of the Grand Cañon to the town of Grand Junction, Colorado (including that portion of the Grand River above the Colorado). This may be called the Upper or Cañon Division.

The Creation of the River.

From the western side of the Rocky Mountain range—speaking only in general terms—the whole country through which the Colorado River runs is a series of terraces and high plateaus, extending as far west as the Grand Wash, or end of the Grand Cañon, where the surface descends to a much lower elevation. This low country reaches to the eastern side of the mountain ranges of Nevada and California, which separate it and the valley of the Lower Colorado from the Pacific Ocean. This high "plateau country" is divided into valleys, terraces and plateaus, ranging in height from 4 000 to 10 000 feet above the level of the sea, with mountain peaks, extinct volcanoes and cinder cones reaching to an elevation of some 13 000 feet or more above the sea.

Geologists tell us that over this whole western part of our continent, during the long geological ages, from the Carboniferous to the Eocene periods, the bed of the great ocean that covered it gradually sank, and as it sank there was deposited under the waters the strata of rock we now see exposed, amounting in all to from 14 000 to 20 000 feet in thickness. About the beginning of the Eocene period there came a turning point in the origin of this part of the continent. First came a great upheaval on the south of the province where the San Francisco Mountains now are in New Mexico. The eastern portion rose gradually, and lastly and more suddenly rose the far west, forming a great Eocene lake, with the older Uinta Mountains on the north, and the Rocky Mountains to the east. Thus what is called the "Plateau Country" was formed into one continuous lake or inland sea, surrounded in the most part by mountain ranges. This plateau lake seems to have been one of the

largest and most enduring of the great lakes of those ages. The volume of sediment accumulated upon its bottom ranged from 1 200 to upward of 5 000 feet in thickness. At length, as the ages rolled on, there was a cessation of this deposit and a beginning of the gradual upheaval of the whole country. An outlet for the elevated waters of this lake was formed in the southern or southwestern portion.

Following the careful and convincing argument of Captain C. E. Dutton, from the evidence which seems clearly to be written, "we must also infer that upon the floor of this basin, as it emerged, a drainage system was laid out. Such a drainage system would necessarily conform to the slopes of the country then existing. Taking the supposition already made, that the uplift was somewhat greater upon the eastern than upon the western side of the province, the configuration of the principal drainage channels would be very much like that now existing. The trunk channel would flow southwestwardly and westward, while the tributaries would enter it on either hand, very much as the larger and older tributaries now do."

"With the final desiccation of the Grand Cañon district began the great erosion which has never ceased to operate down to the present time. Concerning the details of this process we know but little, and we can only guess at its general character during the earlier ages. Erosion is here associated with a large amount of uplifting, and we may conjecture that as the uplifting went on the irregularities produced by erosion became greater and greater, the valleys grew deeper and the intervening mesas stood in high relief."

This earlier upheaval was coincident with the earlier volcanic eruptions, and is roughly estimated at from 2 000 to 3 000 feet.

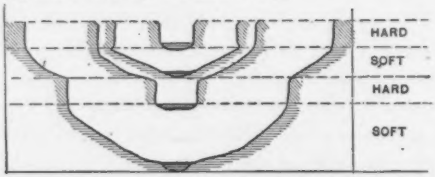
"The river found its base level soon after the uplifting ceased, and the cañons slowly widened by the recession of their cliffs."

As the ages rolled on, quoting again from Captain Dutton, there came "the final upheaval which has already brought the region to its present condition. The Colorado River, after remaining without erosion at the level of the esplanade of the cañon during the greater part of the Pliocene time, at length resumed the operation of sinking its channel. A new paroxysm of upheaval set in; the faults increased their displacement; the volcanic vents reopened. This time the upheaval was greater than before, amounting probably to from 3 000 to 4 000 feet, and the narrow inner gorge was swiftly cut."

"During the last stage of the evolution the Glacial period intervened between the arid climate of the Pliocene and that of the present time. The glacial period here was not icy, but rainy, and very probably colder than the present. In some localities it began to excavate systems of local drainage channels and to carve out minute details of topography."

Thus the process, which was twofold—erosion and weathering—has gone on from age to age. At times the gorge of the main river has been partially filled up by the inflow of great streams of lava from the volcanoes above. In places this lava filled the whole gorge to the depth of hundreds of feet; but the mighty volume of water has cleared out its channel a second time, as if the huge masses of basalt were but piles of chaff and straw, till to-day we have this marvelous river flowing through a stupendous chasm, from 1 to 13 miles wide on top, and at a depth of from 1 000 to 6 200 feet below the general level of the surrounding country, with a system of lateral gorges from one-half mile to a mile in depth, and extending many miles back into the country on either side, and with a fall in the distance surveyed of over 4 500 feet, and containing, in less than 500 miles, 520 rapids, cataracts and falls.

With such a picture as this, it is not surprising that the practicability of building a railway at the bottom of the gorge should be seriously questioned. Before entering upon the discussion of this part of the subject, as bearing particularly upon it, one more quotation will be made from Captain Dutton's valuable book.



Development of Cañon Profiles.*

"Since the attack of erosion, under the conditions prevailing in the plateau country, is mainly directed against the edges of the horizontal strata, and since these strata vary among themselves in respect to hardness or durability, it follows that the different beds would, if the exposures were equal, weather at different rates. The softer beds would disintegrate rapidly and undermine the edges of the harder beds overlying them. The harder beds being robbed of support, cleave off by the joints, and the fragments fall. The fragmental material thus produced

* "Tertiary History of the Grand Cañon District," Capt. C. E. Dutton.

is not immediately carried away, but remains in part and forms a talus."

It is not necessary to quote farther. The nature of this talus for a road-bed will be explained for each separate cañon.

Remembering, then, how these cañon walls were formed in general, and the fact that in the Grand Cañon, where the depth is from 3 000 to 6 200 feet, the width on top is from 6 to 13 miles, some light is thrown upon the supposed perpendicularity of these cañon walls, and the narrowness of their defiles. The important consideration, however, was, what were the details of formation that would affect the construction of a railway in order to take advantage of the easy grades offered by this water course?

No attempt had been made, as far as is known, in the geological surveys to gather and put on record any detailed information as to the nature and formation of the immediate banks of the river, or in other words the lower 100 to 200 feet of what are called the cañon walls. When the question was to be settled as to the practicability of this water-course as a railway route, it therefore became necessary to make a complete examination and survey at the bottom of the cañons along the river itself.

The subject proper will be divided under two heads:

First.—The preparations and outfit necessary for such a work, together with the methods employed in making the survey.

Second.—The results obtained.

In the spring of 1889, the Denver, Colorado Cañon and Pacific Railroad Company was organized for the purpose of making a preliminary survey from Grand Junction, Colorado, the point where the Denver and Rio Grande Railway crosses the Grand River, down the Grand and Colorado rivers to tide-water at the head of the Gulf of California. The promoter of this project, the Hon. Frank M. Brown, of Denver, was made President of the company, and being very enthusiastic on the subject, determined to accompany the engineer corps on all the surveys. President Brown's connection with this expedition, and his sad and tragic death by drowning during its progress, together with two of the boatmen of the party, in the following July, need only be referred to here. The causes which led to such a catastrophe will be stated farther on.

The party left Denver by rail the 22d of May for Green River Station, Utah, where had been gathered together the boats, supplies and necessary

outfit, and consisted—with the writer—of sixteen men: four instrument men, one photographer, two rodmen, two flagmen, two axemen, and one cook, besides President Brown and two guests invited to accompany him.

In addition to the various duties on the survey, each man was expected to act in the capacity of boatman whenever required, and as far as it was possible was chosen with this end in view. It being impossible to transport the supplies for the subsistence of the men in any other way, President Brown had fitted out in all six boats for the expedition. Five of these were ordinary clinker built cedar hunting boats, 15 feet in length, both bow and stern being pointed exactly alike, and decked over about 3 feet back. In each end was fitted a light copper air-tight compartment. The other boat was a common board skiff that had been used on the Grand River survey.

Provisions were provided for three months, it being expected to replenish the supplies at Lee's Ferry, and at Peach Springs. To guard against loss, the provisions were separated into five parts, packed in canvas sacks and so placed that each boat contained almost exactly the same amount of every article of food. All other supplies, instruments, etc., were divided as far as possible in the same manner, except the cooking utensils, which, much to our future sorrow, were all in the last or "cook boat," and were nearly all lost when that boat went to pieces in the rapids. Everything was reduced to the lowest possible weight. No tents or shelters of any kind were taken. Each man was allowed 10 pounds of extra clothing and 15 pounds of bedding. A complete supply of medicines was carried, in triplicate, and packed in three different boats. For the purposes of the survey two complete sets of instruments, transits, levels, rods, chains, etc., were taken; besides an extra transit with solar attachment.

While outfitting the party the question arose how most effectually to do the work so as to clearly present the results not only to engineers, but to capitalists and possible investors.

This question was one of vital import on account of the fact that up to this time the cañons of the Colorado had been considered not only impracticable, but even impossible, for railway purposes, on account of the supposed perpendicularity of their walls.

It was therefore decided to add a new assistant to the corps of engineers in the form of a photographer with a duplicate set of photographic

instruments and some 1 800 films or paper rolls. The work of the photographer in the actual survey will be more fully set out farther on.

The survey from Grand Junction to the mouth of Grand River or head of the Colorado having been previously completed under Mr. Frank C. Kendrick, our party, on the 25th of May, embarked on the Green River, the main branch of the Colorado, at the crossing of the Denver and Rio Grande Railway. This branch was chosen for the purpose of reaching the Colorado on account of there being but one bad rapid in a distance of 120 miles.

This first outfit provided for the expedition was defective in three points. The boats were totally unfit for the work they had to do, no life preservers were provided for the men, and no adequate protection from the water for the provisions. When it is understood that from the point where we embarked to the gulf, the river has a fall of over 4 500 feet, and that in a distance of less than 500 miles contains 520 rapids, cataracts and falls, it will be seen that these defects were of vital importance to the success or failure of the survey.

We reached the head of the Colorado May 29th, and on the 30th took up the survey that had been brought down the Grand River. In order to make clear the nature of the work and the necessity for an entirely new outfit before the survey could be completed, it will be proper to briefly relate a few incidents of the journey from the 1st of June to the middle of July. On the 1st of June we encountered the heavy rapids of Cataract Cañon. It was but a few days till our cook boat was jammed between two rocks in Rapid No. 10, and nearly all of the cooking utensils and a large batch of supplies lost in the river. Disaster followed disaster. All of our boats were badly damaged, two of them entirely gone.

On the 16th of June, by the upsetting of the boats all of our provisions were lost except a sack and a half of flour, a little coffee, sugar and condensed milk. This looked very desperate for a party of sixteen hungry men in such a country as the heart of Cataract Cañon. The next morning President Brown, with a picked boat's crew, started for the placer mines, some 35 or 40 miles down the river, to procure supplies. The scarcity of provisions and the separating of the party alarmed the men, and the greater number decided to desert the work and to follow Mr. Brown, leaving, as they did, their instruments standing upon the line. Knowing that if we abandoned the survey then we could not

return to that point and complete it, and believing that the work could be completed to Dandy Crossing with the food on hand, which was divided equally among all the men, the writer determined not to leave, if a sufficient number of men would remain to assist him. The first assistant, Mr. John Hislop, together with C. W. Potter, one of the flagmen, and the two negro servants, Henry C. Richards and G. W. Gibson, the cook, volunteered to remain and continue the survey. These men deserve special mention and praise for the faithful and uncomplaining manner in which they pushed on the work till the evening of the 20th. It requires more than ordinary nerve to do the work of an engineering party over such a country with only about one-tenth the amount of solid food that a healthy man requires.

On the evening of the 20th the party was met by a relief boat with supplies from the placer mines, and soon completed the survey to Dandy Crossing. At this point a reorganization of the force and work was decided upon. Mr. W. H. Bush was left with one party to carry the survey through Glen Cañon, as far as Lee's Ferry. President Brown, the writer, the photographer and five men with three of the cedar boats started, in accordance with President Brown's desire, to make a rapid examination of the lower cañons, doing no instrumental work except that with the camera. This advance party reached Lee's Ferry July 2d, and remained seven days waiting for new supplies. July 9th it left Lee's Ferry and entered Marble Cañon. The next day, while running Rapid No. 108, the first boat was upset, and in less than two minutes after starting from the shore President Brown was drowned. He had no life preserver and it is practically impossible for one to swim in those surging waters without some such assistance.

Being very desirous to complete the work, the writer concluded to push on, even then not fully appreciating the utter worthlessness of the boats and other means provided for making such a journey. On July 15th another accident in Rapid No. 133 upset one of the boats, and the two boatmen, Peter M. Hausbrough and Henry C. Richards, were both drowned. It was then decided to abandon the attempt to go farther down the river, and to return to Denver, every one of the party determining as soon as a new and proper outfit could be secured to again take up the work and complete the survey through the cañons. All supplies, instruments, etc., were cached in a marble cave about 40 miles below Lee's Ferry, and after some hard climbing out of the gorge, we reached

the Mormon settlements north of the river, and on the 27th of July the remnant of the expedition arrived at Denver.

The Second Outfit.

The writer immediately set about preparing for a second expedition. Profiting by the sad experiences of the summer before, the new outfit was vastly different from the first. From special plans, the R. J. Douglas Company, of Waukegan, Ill., built three boats for this second expedition. They were entirely of oak, 22 feet long, 4½ feet beam and 22 inches deep. The ribs were 1½ x ¾ inches, placed 4 inches apart and planked with one-half-inch oak, with butt joints calked with oakum, the whole riveted together with copper rivets. Both ends were built exactly alike, decked over 3½ feet back, and a deck 6 inches wide ran along on each side. At each end were water-tight lockers for storing supplies, above these under the decks air-tight compartments made of heavy galvanized iron, and along the sides, under the 6-inch decks, were placed four air-tight tanks of the same galvanized iron. These side tanks extended down about 10 inches under the water line when the boats were fully loaded. Fitted in this way, with ten separate air-tight compartments in each boat, it was found, even in the roughest water, that they could not be upset, and when loaded with 3 200 pounds in each and filled with water they would not sink (Plate XXVII).

The boats were fitted for two oarsmen using 8-foot oars, and steered with a 12-foot oar. Along each side was fitted a strong life line. To the bow was attached one short 20-foot line and one long one 250 feet for the purpose of letting the boats down the rapids when it was impossible to run them; to the stern was one 50-foot line, all of them five-eighths inches in diameter. In each boat was carried a small set of carpenters' tools, copper rivets, nails, screws, oakum, pitch and sheet copper for repairs.

All provisions, clothing and supplies, except bedding, canned goods and meat, were packed in forty-eight heavy rubber bags made expressly for this expedition. They were 12 inches in diameter and 20 inches long, with mouthpieces 16 inches in length (Plate XXVIII). After the bag was filled this mouthpiece or flap was folded and rolled very tight and laced over with strong lace cord; over them was then fitted a strong canvas sack to save the rubber from being chafed. These bags when laced tight were found to be very effective in excluding the water, one boatload being

under the water for several hours without injury. Besides these rubber bags, in each boat were fitted, in special compartments near the bow, two 5-gallon kegs, filled with rice, beans, sugar, coffee, etc.; this as a special precaution against accident, as they would float, while the bags would sink. As before, all supplies, including this time the cooking utensils, were divided equally between the three boats. A supply of medicines, rifles, shot guns, ammunition, etc., was taken. Expecting to be out all winter four small tents were provided; but these were soon thrown away as being a cumbersome luxury. On account of the winter weather more blankets, overcoats and clothing were necessary. Four months' provisions were taken at the start, and each boat carried when fully loaded about 3 200 pounds, besides the four men. A false bottom was placed in the boats, under which all canned goods were packed next to the keel, with the salt meats and hardware in the lockers at each end. Everything was so packed and strapped to the boats that in case of an upset nothing could be detached unless the boat was completely smashed.

The new photographic supplies consisted of two 6½ x 8½-inch cameras and one 4 x 5-inch detective instrument, and 2 000 films in rolls with extra roll holders. Each roll of films was soldered up in a tin box and these packed in the rubber bags. As each roll was exposed it was again soldered up in the tin boxes and the duplicates carried in separate boats. All necessary instruments, transits, levels, rods, barometers and thermometers were, of course, supplied. The best cork life preservers were provided for all the men, and they were required to wear them whenever on the water. These life preservers proved of greatest service. Mr. John Hislop, the first assistant, and the writer were both thrown from their boats while running the rapids, and their lives only saved by such assistance.

The party consisted of twelve men in all: Mr. John Hislop, first assistant; Mr. Harry McDonald, Mr. Langdon Gibson, Mr. Elmer Kane, Mr. F. A. Nims, photographer; Mr. Reginald Travers, Mr. W. H. Edwards, Mr. A. B. Twining, Mr. H. G. Ballard, Mr. L. G. Brown, Mr. James Hogue.

Only six, besides the writer, went through the cañons to the end of the journey. Mr. Nims, photographer, broke his leg January 1st, 1890, and was left at Lee's Ferry; McDonald left of his own accord in February, after reaching the Grand Cañon; Twining, Brown and Hogue,

PLATE XXVII.
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having lost their boat, were sent out at Peach Springs. The men remaining were chosen for the double duty of an engineer corps and as boatmen to navigate the river.

This second expedition was completely successful in every way, accomplishing the journey to the gulf without disastrous mishap. To avoid the unnecessary hardships of Cataract Cañon, the boats were hauled by wagon 120 miles from Green River Station to the mouth of Crescent Creek, 4 miles above Dandy Crossing. The expedition embarked December 10th, reached the mouth of Diamond Creek March 1st, emerged at the lower end of Grand Cañon March 17th, reached the end of the survey at tide-water April 26th, and returning to Yuma was disbanded on April 30th. One boat was completely destroyed in Rapid No. 249; but only two sacks of provisions were lost in the whole journey.

Thus had the two expeditions, considered as one, traveled by boat a distance of over 1 400 miles, had passed over—running nearly all of them—520 rapids, falls and cataracts in less than 500 miles, making a total fall of 4 500 feet, and had passed successfully through the dark cañons of one of the most tempestuous rivers of the world.

Methods Employed in Making the Survey.

The maps of the Government Geological Survey gave the general course and length of the river, its fall by sections, and all the general information required. What was needed, however, to settle the practicability of this as a railway route, was detailed information upon the alignment and fall of the river, the nature and material of which its banks were formed, and careful inspection of the lower 100 or 200 feet of the cañon walls. It will be readily seen that much of the work usually done on a preliminary survey might be dispensed with, and much other work of a very different character would be required.

For the purposes of right of way, a continuous transit line was run for the first 355 miles. Over 600 miles of transit line was run altogether. Such work was done at all points where there was any question as to possible difficulty of curvature. Where long stretches of the river occurred with slight curvature, such work was not thought necessary.

All measurements were made by stadia, and triangulation. On all transit lines run contour topography was sketched. Levels were only taken at points where excessive fall in the river required a settlement

of the question of grade, or at points where the line would require sharper grades to cross long bends or rise from one ledge to another. Where the average fall of the river did not exceed 10 to 12 feet per mile, and there did not occur any reason why a road-bed should not follow nearly parallel with high water mark, no such work seemed to be required. For a very large proportion of the whole distance there was no difficulty in the way of running a line along the shore in the usual way without the use of boats. This will be readily seen by an inspection of the photographs. At other points the work could only be accomplished with the help of the boats.

In those portions of the river where the rapids were heavy and thick, it was the usual method to take the boats ahead, make camp, and return along the shore for the line, which was carried ahead of the camp. In the smooth portions of the river, in Narrow Cañon, all through Glen Cañon, and on the lower river below the cañons, the first boat carried the front flagman ahead, the second boat brought the transitman and photographer up to the next station, and the third boat assisted the topographer and did other special work. Permanent backsights were set up at all turning points. On some occasions when for special reasons only one boat could be used many devices by triangulation, not necessary to be described, were employed to carry on an accurate line.

Careful readings of the barometer and thermometer were taken three times each day. In addition to the usual notes kept by the transitman, leveler and topographer, the writer kept an extensive series of notes, as much in detail as possible. Besides a record of all the work done upon the river, these notes covered a careful description of each section of the shore line (connected by numbers with each of the photographs as taken), its form and general appearance, with numerous sketches showing cross-sections and peculiar forms, requiring special work, careful classification of all material in each section, a record of every waterway required, from 10 feet opening up, with a general description of the whole country, and its bearing upon a railroad line as to its grade, alignment, methods of construction, nature of the road-bed, and requirements for maintaining the permanent way. These notes cover nearly two thousand pages. The system adopted for classification was not that generally used on construction, as no estimate was possible or necessary in cubic yards, but a classification into kinds or classes of work. For example: Level bottom lands, hillside slopes,

rough talus slopes, smo[illegible]olid rock slopes, cliff bench[illegible]k, heavy through rock cuts, heavy embankments, rock bluffs, tunnels, vertical cliffs and half tunnels.

It is believed that this [illegible]ssification, with the numerous photographs, will give a clear understan[illegible]g of the whole nature of the work.

This brings up for consideration one of the most important features of the survey. While photography had been used in many ways to illustrate engineering works, it is believed that never before had the camera taken so active and important a part in making a preliminary railway survey and exploration through a hitherto almost unknown land. As intimated above, the object to be attained was to bring back indisputable evidence of the nature and possibilities of a country practically inaccessible except through dangers to both life and limb. The process was very simple. Photographs were taken in such number all along the line as to show almost a complete panorama of the river banks and the walls of the cañons, from the head of the Colorado to the Gulf of California. Through the most difficult portions these pictures were taken so as to overlap each other and leave no detail of difficult construction without its negative to supplement and demonstrate the notes and opinions of the engineers. This continuous panorama was not carried out in full over the whole distance for several reasons. During the stampede of the first expedition, only a few photographs were taken in the lower Cataract and Narrow cañons. The work there, however, being so uniform in its character, the pictures taken fully illustrated the work when used in connection with the instrumental and other notes. On the lower river, where, for miles at a time, the line would run over identically the same formation, pictures were taken less frequently.

About 2 200 negatives were taken in all, most of them in duplicate and some in triplicate. Nearly 1 000 views were secured that illustrated the route. These views, arranged in their order, noted on the maps, and connected by numbers with all notes, are of such value as not only to convince the most incredulous of the entire practicability of the route, but also cover the line so in detail that, with the notes of distances and classification, will enable engineers anywhere, familiar with rough mountain construction, to make as correct an approximate estimate of the cost of such a road as can those who accompanied the expeditions.

It is a notable fact that while the President of the Company and two

boatmen were drowned, provisions, instruments and boats destroyed, not a single negative was lost in the river. Of course, special care was taken to preserve them; yet it is almost marvelous that during the many disasters and mishaps, this most valuable evidence was kept from even being wet. As noted, the photographer, Mr. Nims, who did all such work down to the middle of Marble Cañon, fell January 1st and broke his leg. No other man in the party had ever taken a photograph. It was with much anxiety and misgiving, on account of the importance of securing pictures of the Grand Cañon, which was still below, and the most important section of the river, and the utter impossibility of securing in time another professional operator, that the writer undertook the work; for he had never before as much as focused a camera.

It may not be out of place to note here, that while exposing his first negative, and while in the act of dashing his hat upon the ground and tearing his hair in his excitement and perhaps rage at his complicated situation, the cook took a snap shot at him with the "detective" and preserved for his future contemplation the absurd picture he was making of himself. Twelve hundred exposures were made without his being able to see a single developed negative, as all such work was done afterward in Denver, but it is gratifying to state that out of the whole number taken only about 10 per cent. were not clear pictures, and this 10 per cent. were sufficiently clear to be used to illustrate the survey.

The first work done on starting the survey at the head of the Colorado, was to establish a true meridian. This was done at various points for the purpose of checking the instrumental work. The results were very satisfactory, and reflect much credit upon Mr. John Hislop and Mr. W. H. Bush, for the accuracy with which they handled their instruments under so many trying circumstances.

It may not be out of place to record one experience of the writer's peculiar to the depths of these wild gorges. It was the burden of anxiety ever pressing upon him that a mile might be passed over and important features not be sufficiently observed and noted at the time, for the reason that while in his many experiences in exploration in the Rocky Mountains, if an item or two were forgotten, it was but a matter of a day and some hard climbing to correct the error, yet here in these awful cañons, with death staring the party in the face at almost every rapid, it was impossible to return. And especially was this the case in the winter, when, while the wild flowers were in bloom in the valley be-

low, the plateau above was covered with from 3 to 6 feet of snow, and in case of loss of provisions, worse than death was in store for those who attempted to retreat.

In the description of the river line and nature of the country, the names and divisions of the cañons will be used as adopted in the Government reports. The river course is divided into various cañons, though these divisions are entirely arbitrary. No natural marks of separation exist, except at the end of Glen Cañon, at the crossing of the river known as Lee's Ferry.

The Results of the Survey.

The whole subject under consideration has been divided under two general heads:

First.—The feasibility and practicability of the route for a railway line.

Second.—The advisability of such a railway.

For the purposes of this paper only the first of these will be considered at any length.

Under the first general head are the following subdivisions:

A—Detailed description of the line, giving the nature and character of the material encountered along the river banks.

(1) The Grand River Division, from Grand Junction to the head of the Colorado.

(2) The Cataract and Narrow Cañons, from the head of the Colorado to Dandy Crossing.

(3) The Glen Cañon, from Dandy Crossing to Lee's Ferry.

(4) The Marble Cañon, from Lee's Ferry to the Little Colorado.

(5) The Grand Cañon, from the Little Colorado to the Grand Wash.

(6) From the Grand Wash to the mouth of the Rio Virgin.

(7) From the Rio Virgin to the Las Vegas Wash.

(8) From Las Vegas Wash to The Needles.

(9) From The Needles to the Town of Yuma.

(10) From Yuma to the head of the Gulf of California.

B—Statement in tabulated form of the results of this detailed survey.

C—Methods of handling such a work in so difficult and inaccessible a country.

D—The nature of the line itself.

(1) The grades.

(2) The alignment.

(3) The distances.

(4) Maintenance of the permanent way.

(1) The Grand River Division.

From the notes and maps furnished by Assistant Engineer Kendrick the following statements of this division are compiled.

It must be borne in mind that during the survey down the Grand River no photographs were taken. The general class of work being known, however, it can be well illustrated by pictures taken further down the river.

From Grand Junction the line follows parallel with the Rio Grande Western Railway down the valley of the river 13¼ miles, when it turns due west, and in less than two miles reaches the bank of the river. Following along the right bank of the river, on alternate stretches of bottom land and hillside slopes of talus (loose and solid rock), to a point about 22 miles from the beginning, the line crosses Grand River, and in cutting off a long bend uses the first and longest tunnel on this division. This tunnel would be 5 900 feet long and save a distance of nearly 4 miles of heavy work. Keeping, then, upon the left bank of the river, there follows the same succession of bottom lands, hillside slopes and talus of loose rock, with occasional rock bluffs and short cliffs requiring heavy work.

Beyond here the river enters the Granite Cañon of Grand River. Mr. Kendrick did not make his survey through this gorge, but followed the high plateau over which the Rio Grande Western Railway runs to the neighborhood of the "Sisco Pumphouse." A final located line would, however, pass through this Granite gorge. From the point opposite the Sisco Pumphouse the survey followed the bank of the river, the work being heavier with an increased proportion of solid rock excavation, and a second tunnel of 3 000 feet, cutting off another long bend of the river. Seventy-five miles from the starting point the Little Castle Valley, a rich agricultural district, is reached. Through this valley there are 10 miles of earthwork. For 15 miles farther on are found the same hillside slopes and talus of earth and loose rocks, and points of cliff and solid rock bluffs. The nature of these slopes

will be more particularly described and illustrated by photographs later on. The line passes the Little Grand Valley, another farming district, beyond which, and nearly all the way to the head of the Colorado, the Grand River is much more tortuous, and there are long bends returning upon themselves. A succession of four tunnels, respectively 3 200 feet, 3 000 feet, 4 000 and 2 700 feet in length, with the two tunnels described above, and aggregating $4\frac{11}{100}$ miles, save a total distance of $23\frac{1}{2}$ miles. In the last 36 miles of the Grand River Division there are 6 miles of bottom lands, and a large proportion of light hillside work of earth and loose rock, given in Mr. Kendrick's estimate as "pick and shovel work."

TABLE OF CLASSIFICATION IN MILES FROM GRAND JUNCTION TO THE COLORADO RIVER.

DISTANCE IN MILES.	GENERAL CHARACTER OF WORK.	Characteristic photographs illustrating each class of work.
36.323	Level bottom land, earth, gravel, etc	Nos. 25 and 33
19.273	Hillside slopes, E. & L. R.	Nos. 40 and 48
61.035	Rough talus slopes, L. R. & S. R.	Nos. 52 and 69
6.206	Solid rock slopes	No. 91
13.040	Granite walls	See Grand Cañon Pictures.
4.110	Tunnels	
139.987	Total	

NOTE.—Photographs selected from those taken on the Colorado.

It would be impossible in such a paper as this to reproduce all the photographs whose numbers are used to illustrate these tables, much less the 900 or 1 000 views accompanying the writer's report to the railway company. As soon as it can be prepared it is the intention of the writer to present to the Society an album of all these views for preservation in its library. These views will be arranged in order and numbered correspondingly to the numbers given here.

As stated above under the description of the methods employed, the measurements, notes and descriptions of the route along the Colorado were taken so as to show the nature of river bank or cañon wall, and the class of material of which it was composed for each 100 feet, if any change in its character or form occurred so often, and at each point where such change was noted, one or more photographs were taken to completely illustrate it. These notes, covering nearly 2 600 pages, were

then tabulated, giving the length of each piece of work, and different class of work, in the order of their occurrence, in this form, starting at the head of Cataract Cañon:

21 050 feet level bottom land.

2 400 feet rough slopes, L. and S. R.

2 700 feet heavy embankment under cliff.

13 400 feet hillside slopes.

4 000 feet level bottom land.

These tables covered many pages. They are not necessary, in so detailed a form, to the understanding of the subject, and will only be given here in condensed tabulated form, with general descriptions of the more marked characteristics of the several cañons and subdivisions.

(2) The Cataract and Narrow Cañons.

The length of this division, from the head of the Colorado to Dandy Crossing, is 54.214 miles.

Condensed Table of Classification in Miles, Cataract and Narrow Cañons.

Miles.	General Character of Work.	Characteristic photographs illustrating each class of work.
11.543	Level bottom land	Nos. 39 and 114
5 436	Hillside slopes, E. & L. R.	Nos. 48 and 78
14.545	Rough slopes, L. R. & S. R.	Nos. 52 and 69
2.557	Solid rock slopes	No. 106
19.110	Cliff bench work	Nos. 85 and 90
.739	Heavy embankment under cliff	No. 44
.284	Tunnel	
54.214	Total	

Some marked characteristics in this division deserve special notice.

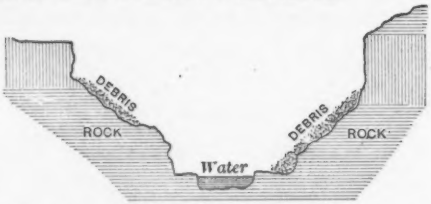
1st. The large amount of bottom lands consist of flats formed at the bottom or foot of the generally sloping walls. They are composed of earth gravel and small loose rock. In places large detached rocks from the cliffs above lie upon these flats, but not to such an extent as to change their character from that of earthwork (Plate XXIX). See Photos. 30 to 38.*

2d. The "Hillside Slopes" are formed of the same materials, with a

*The photographs referred to throughout are to be deposited at the house of the American Society of Civil Engineers for reference.

larger proportion of loose rock. In many cases these slopes are simply decomposed and broken rock covering a slope of the original formation of stratified rock in place. This is of the "softer" sandstone, and generally in horizontal layers. See Photos. 77 to 78.

A cross-section in this formation is thus shown:



At other points the earth and loose rock compose the whole slope, but are well cemented together, and would form a secure and solid roadway. See Photos. 70 to 76.

3d. The "Rough Slopes" are of the same nature, but formed of much more coarsely broken rock and boulders.

4th. At but one point on this division does there occur any really perpendicular cliff that interferes with the railroad line. This is passed by the 1 500-foot tunnel.

5th. Beyond this tunnel point the character of the cañon walls changes entirely. The gorge is much narrower, and in many places the cliffs rise vertically from the water, and frequently overhang from 10 to 30 feet. They vary from 20 to 80 feet in height from low water to the first bench, and above this is a slope to the next cliff, which varies in height as the one below. These slopes or benches are of different widths, generally about 50 feet wide.

The rock is a very hard sandstone above, with limestone ledges next to the river. Occasionally two or more benches are broken together, forming a slope down to the water. This character of "cliff bench work" predominates through the remainder of Cataract and Narrow cañons.

For a distance of nearly 6½ miles the cañon is narrow, from 250 to 450 feet between lower walls. The benches have generally low cliffs—25 to 40 feet—between them, the first rising directly from the water's edge. These cliffs are mostly of solid, hard limestone. In places the cliffs are ragged and broken into points, and occasionally stand out into the river in bold bluffs; these will require to be blasted away and thrown into the

river. See Photos. Nos. 87, 88, 89 and 90. In a few places the second and third benches are broken down, so that the first bench is very wide and the line would be located well back from the river.

6th. At the lower end of Narrow Cañon a new formation comes in. The limestone has sunken under the river, and a massive red sandstone forms smooth, naked slopes. This first occurs opposite the mouth of the Dirty Devil River. See Photos. Nos. 100 and 101.

High and Low Water.

From the head of the Colorado to Dandy Crossing the difference between high and low water mark varies from 25 to 60 feet, and perhaps in places even more than this, the greatest difference being, of course, in the narrow parts of the Cataract and in the Narrow cañons. In those portions where the walls stand vertically from the water, the exact high water mark is hard to determine. From the very nature of the case, however, this point is almost entirely below the lower edge of the first bench; for the extreme rise is caused by the extreme narrowness of the bottom gorge, and the perpendicularity of its walls. The railway line being necessarily here located on the upper part of the first bench, and in some places on the second, in this narrow portion will be well above high water, and for nearly the whole distance upon a solid rock road-bed not affected by the rise and fall of the river.

(3) Glen Cañon.

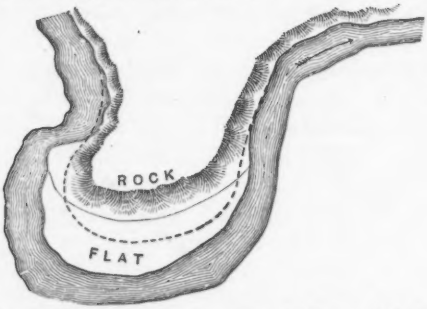
This division has some peculiar features not found anywhere else on the whole route. It will therefore be best to explain its characteristics before giving the detailed table of classification.

First.—The average fall per mile of the river in Glen Cañon, that of 2.17 feet, is less than in any other portion above the mouth of the Las Vegas Wash.

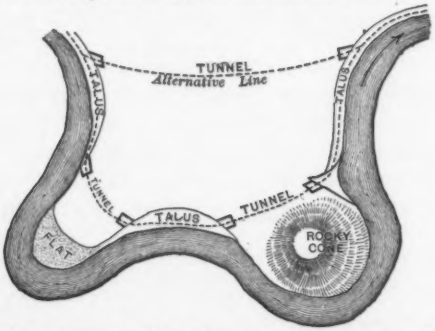
Second.—This light fall has formed for the greater part of the way a very wide channel, in places as much as 1 800 feet, and has allowed the formation of a large amount of bottom land. These flats or bottoms are very extensive and in many places very wide. They are above all ordinary high water, and it is believed above extreme high water at this time. On account of the excessive crookedness of the river in this cañon some of these flats are peculiarly situated. Sketch made June 29th illus-

trates this—the flat being at the extreme end of the long bends. Others extend from 1 to 5 miles in length in straight lines and gentle curves. These flats are all earth-plow and scraper work. See Photos. Nos. 134 and 135.

Third.—Through nearly all of Glen Cañon the walls are of a massive red sandstone standing in vertical cliffs. For many miles under these



cliffs there is a high, solid and permanent talus. This is a true talus, composed entirely of broken rock, but on account of the extreme width of the river, and its gentle fall is perfectly secure and adapted for a secure road-bed. In the lower part of this cañon the river is very tortuous and in places has washed away the talus, and it becomes necessary to build a roadway at the foot of the cliff in the river.



Fourth.—On account of this extreme crooked course of the river in Glen Cañon, it is necessary, in order to locate a good line, to use a large number of tunnels. The survey was made following the river bank and the tunnels located by platting. In this way two lines were estimated; the first requiring seventeen tunnels ranging from 200 to 4 640 feet in length,

and the second or alternative line having nineteen tunnels ranging from 200 to 6600 feet in length, this last line making a saving of 18½ miles in distance. The nature of these two lines in this respect is well illustrated by the sketch on page 307.

Which of these two lines is the better can only be determined by a careful location and a proper comparison of estimates in dollars and cents. The tunnels would be through the massive red sandstone, soft enough to make cheap work, and yet hard enough, as is shown by the vertical cliffs, to stand for many years without requiring either timbering or arching. As bearing materially upon both the cost of construction, and the maintenance of such a line, the following condensed tables are given of classification of both main and alternative lines and comparison of tunnels:

From Dandy Crossing to Lee's Ferry by main surveyed line..... 156.580 miles.
By alternative "B"..... 138.100 "

CONDENSED TABLE OF CLASSIFICATION—GLEN CAÑON.

MILES.	GENERAL CHARACTER OF WORK.	Characteristic photographs illustrating each class of work.
57.270	Level bottom lands.....	Nos. 134, 212.
10.928	Hillside slopes, E. & L. R.....	" 141, 155, 174.
55.926	Rough talus slopes, L. & S. R.....	" 178, 233.
21.284	Solid rock slopes and bluffs.....	" 179, 318.
6.853	Heavy embankment under cliff.....	" 209, 210.
.501	Heavy through rock cuts.....	" 197, 260.
4.118	Tunnels (17).....	" 241, 242.
156.580	Total.	

ALTERNATIVE LINE "B"—GLEN CAÑON.

MILES.	GENERAL CHARACTER OF WORK.	Characteristic photographs illustrating each class of work.
47.576	Level bottom land.....	Nos. 134, 212.
10.473	Hillside slopes, E. & L. R.....	" 141, 155, 174.
45.519	Rough talus slopes, L. & S. R.....	" 178, 233.
17.812	Solid rock slopes and bluffs.....	" 179, 318.
5.417	Heavy embankment under cliffs.....	" 209, 210.
.445	Heavy through rock cuts.....	" 197, 260.
10.858	Tunnels (19).....	" 241, 242.
138.100	Total, making a saving of 18¼ miles by using longer tunnels.	

LENGTH OF TUNNELS—GLEN CAÑON.

Surveyed line—length in feet.		Alternative Line "B."—Length in feet.		
1	300	1	300	
2	500	2	500	
3	1 000	3	6 600	
4	550	4	4 000	
5	1 500	5	4 500	
6	4 000	6	4 000	
7	200	7	200	
8	800	8	800	
....	....	9	6 000	
....	....	10	4 600	
9	1 000	11	1 000	
10	350	12	350	
11	300	13	2 640	
12	700	14	5 300	
13	4 640	15	4 640	
14	600	16	600	
15	500	17	5 300	Distance saved by using the tunnels of Line "B," 18½ miles.
16	1 500	18	2 000	
....	....	19	4 000	
17	3 300			
4.118 miles.		10.858 miles.		

In concluding the notes on Glen Cañon two points deserve special mention. For about one-half of the 45 to 55 miles of "rough talus slopes" in the estimate, the massive red sandstone stands up above the second stratum of softer rock, and this forms a slope at about 45 degrees of thin horizontal layers of sandstone in place, only covered with a few feet of débris from above, thus reducing largely the amount of embankment to be protected from the river. See Photos. Nos. 173 to 179.

The great width of this cañon reduces the difference between high and low water to a minimum. It varies from 6 to 30 feet.

(4) MARBLE CAÑON.

Through Marble Cañon, and all the rest of the route to the gulf, the dividing lines between the different classes of work are not so distinctly drawn as in the cañons above, as can readily be seen from the photographs. The classification was therefore divided directly, as near as possible, into miles and parts of miles.

The distance from Lee's Ferry to the Colorado Chiqueto, or Little Colorado, is 62.510 miles. A distance of 3 miles is saved by tunnels.

CONDENSED TABLE OF CLASSIFICATION—MARBLE CAÑON.

MILES.	GENERAL CHARACTER OF WORK.	Characteristic photograph illustrating each class of work.
.500	Bottom lands	Nos. 357, 364.
26.510	Heavy talus slopes. See note	" 275, 365.
.125	Heavy through rock cut	" 273, 323.
32.250	Cliff bench work	" 318.
.750	Heavy embankment under cliff.	
2.375	Tunnels (4).	
62.510	Total.	

NOTE.—Under "heavy talus slopes" are placed all slopes of talus and stratified rock in place covered by loose rock and débris.

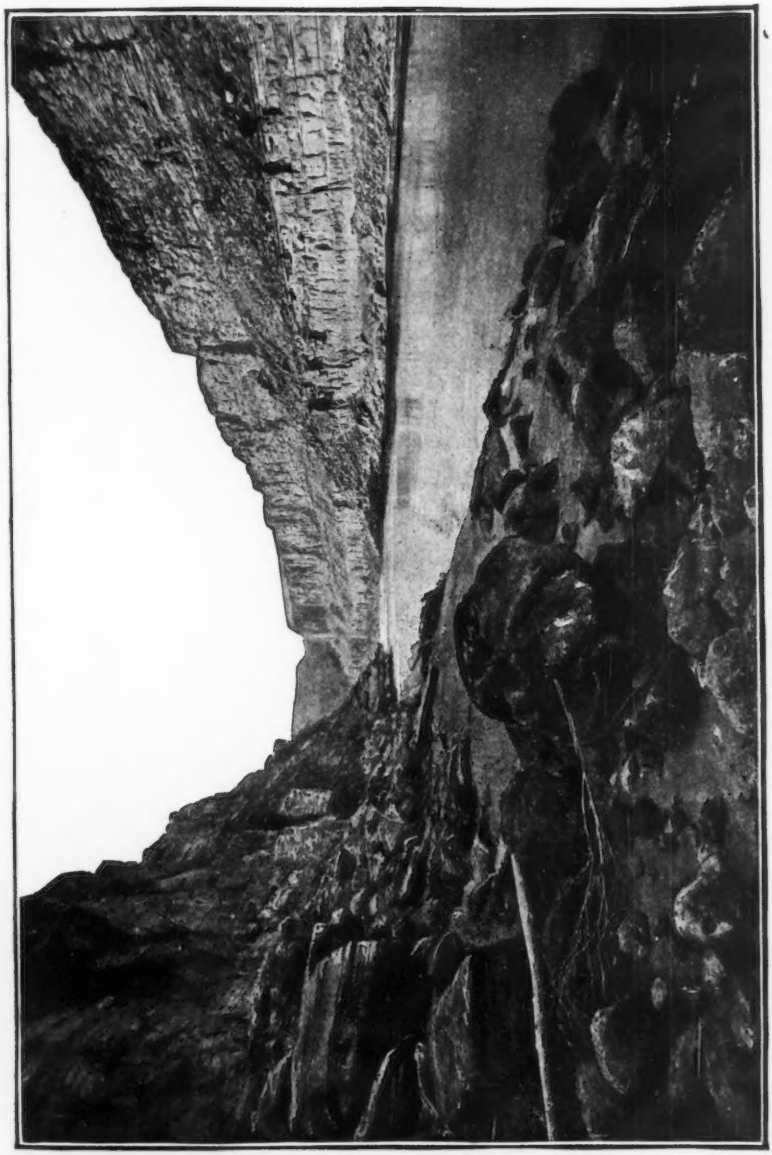
There is now for consideration the one great cañon of the Colorado, although it is arbitrarily divided at the mouth of the Little Colorado into two—the Marble and Grand.

First.—The walls of Marble Cañon are composed of various strata of limestone—in places these have been turned into true marble. The strata are of different degrees of hardness, lying upon each other, first a hard, then a soft, and so on. The softer strata are almost always composed of thin layers of horizontally stratified rock, and they have worn away in slopes from 30 to 50 degrees from the horizontal. These slopes of rock in place are covered with loose broken rock or débris. This is the nature of the 26½ miles of "heavy talus slope" given in the table, and also of a large part of the 32¼ miles of "cliff bench work" (Plates XXX, XXXI). See Photos. 273 to 282, inclusive.

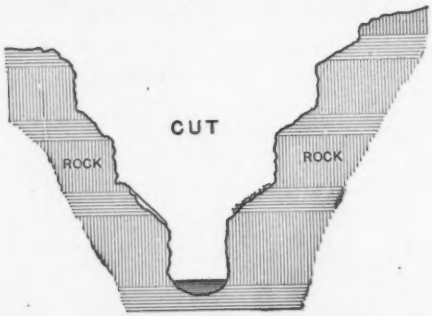
Second.—The cliff bench work only differs from the talus slopes in the fact that the line is located on the slope above a vertical cliff from 50 to 100 feet above the water. This class of work is very noticeable about ten miles below Lee's Ferry, where the river cuts into a much harder stratum of rock, forming a narrow inner gorge, with vertical walls next to the water. Above these walls the cañon slopes back in a general cross-section of this form: (See next page and Photos. 287 to 294.)

In this inner gorge, being so narrow, the difference between low and extreme high water varies from 40 to 95 feet, but from the very nature of the case, a railway line would be located on the first sloping bench above the inner gorge, and well out of the way of the most extreme rise.

PLATE XXX.
TRANS. AM. SOC. CIV. ENGS.
VOL. XXVI, NO. 523.
STANTON ON CANONS OF THE COLORADO.



Third.—At about the middle of Marble Cañon, which has been called Point Retreat, the river makes a sharp turn to the left and then again to the right. At this point the marble stands up in vertical cliffs about 300 feet high from the water's edge, while the sandstones bench back in



slopes and cliffs to 2 500 feet in height. Just beyond this the cañon is narrowest, being a little less than 400 feet from wall to wall. The marble rapidly rises till it stands in perpendicular cliffs 700 to 800 feet high, with patches of broken down cliff forming small benches and talus slopes at their bases. See Photos. Nos. 324 to 338, inclusive.

A located line would pass through Point Retreat with a tunnel about 1 mile in length, cross the river with a single span (Photo. 330) from cliff to cliff, and through the opposite point with a shorter tunnel, coming out upon the same general class of cliff bench work. This section of some 10 miles (two above Point Retreat) in Marble Cañon is, in fact, the most difficult to locate, and perhaps the most expensive 10 miles to construct anywhere upon the whole river. It is necessary to cross the river for the first and only time. The closeness of the marble cliffs offers a very suitable place for a single span bridge. Although expensive, a permanent and first-class line can be located through this 10 miles. Beyond this section of tunnels and bridge the same cliff bench work continues for about 12 miles, with a tunnel through Point Hausbrough, saving a mile in distance. (See Photos. Nos. 332 to 348.) For the last 17½ miles above the Little Colorado the cañon widens, the marble benches retreat, new strata of limestone, quartzite and sandstone come up from the river, forming successive slopes and benches. The slopes are at an angle of about 40 degrees from horizontal, formed of thinner layers of rock in place, and covered with débris. Some of

these slopes rise gradually from the water's edge to a height of from 200 to 1 000 feet. See Photos. Nos. 349 to 372, inclusive.

(5) The Grand Cañon.

The Grand Cañon of the Colorado has been pronounced by those who have carefully studied it to be "by far the most sublime of earthly spectacles." While this perhaps is the case, and while it is one of, if not the grandest gorge on the face of the earth, neither its grandeur nor its dimensions have anything whatever to do with the possibilities of building a railway through it. The fact that the Grand Cañon is 218 miles long—from the Little Colorado to the Grand Wash—and in cutting its way through the Kaibab Mountains the river has formed a chasm from 5 000 to 6 200 feet deep, and from 6 to 13 miles wide on top, has nothing to do with the case whatever. It is only the lower 200 feet or so of the cañon that a railway would have anything to do with directly, but in order to show the nature of this lower 200 feet, and its indirect connection with that above, a general description must be given of the whole gorge.

This cañon is divided into smaller sections by marked changes in the character of its formation as follows:

1st. 18 miles above the granite.
2d. 35½ " of granite.
3d. 35½ " to the Kanab Wash.
4th. 21 " of narrow marble benches.
5th. 54½ " to the lower granite.
6th. 39 " of granite.
7th. 14½ " to the end of the cañon.

This first 18 miles is in fact no cañon at all. The whole country is broken up and back for many miles from the river, and hills and knolls rise up between it and the outer walls beyond, these being separated by washes and gulches running in every direction.

Taken as a whole, the river runs through quite a wide valley. By an examination of Photos. Nos. 376 to 413, inclusive, and the table of classification, it will be seen that all classes of work exist, from earth to cliff bench work, but the larger proportion being comparatively light work.

The second section of 35½ miles of granite walls is the first real cañon portion of the great gorge. As compared with other well known

cañons in the Rocky Mountains through which railways have been built —the Royal Gorge of the Arkansas and Clear Creek Cañon—this has a form peculiar to itself. Its walls start from the water's edge with generally a few feet—10 to 50—of vertical cliff, and then slope back in a ragged, irregular slope 300 to 1 200 feet or more, at an angle varying from a few degrees to 45 degrees from vertical, with some small patches jutting out boldly into the river and towering hundreds of feet high, forming almost perpendicular cliffs, or, more accurately speaking, they form buttresses and towers to the general slope of the wall. Above the granite rise the sandstone, limestone, marble and higher sandstone ledges in cliffs, benches and slopes, stepping up and back till the chasm is from 6 to 13 miles wide. The lower granite walls, with which we have to do directly, are divided into two distinct classes. Those from the head of the gorge to the Bright Angel Creek are mostly of hard massive gray and red granite, and stand in solid, bold slopes. At the Bright Angel this granite changes into a softer kind, generally black and gray, much broken, cut into sharp pinnacles and crags, and seems as if formed of closely stratified slate. The slopes are much flatter and more cut up by side washes, and the whole country opens back into the widest portions of the Grand Cañon (Plates XXXII, XXXIII). See Photos. Nos. 414 to 540, inclusive. In this section were noted four short tunnels aggregating one-half mile.

The section of 35½ miles from the granite to Kanab Wash assume an entirely new form. The granite, except in a few patches, has sunk under the river, and the softer strata of sand and limestones, which form the great slopes above the granite, have come down next to the river, and rise from the water's edge in great talus slopes (underlaid with the same horizontally stratified rock in place) of from 300 to 600 feet high, at a general angle of 40 degrees from vertical. The high cliffs of marble and red sandstone bench back from the tops of these slopes. Although these outer peaks and cliffs have drawn in close upon the river, the cañon itself, that is, the inner gorge, is much wider than above, being measured from the tops of the great talus slopes. This section is shown by photographs (Plate XXXIV). See Photos. Nos. 541 to 597, inclusive.

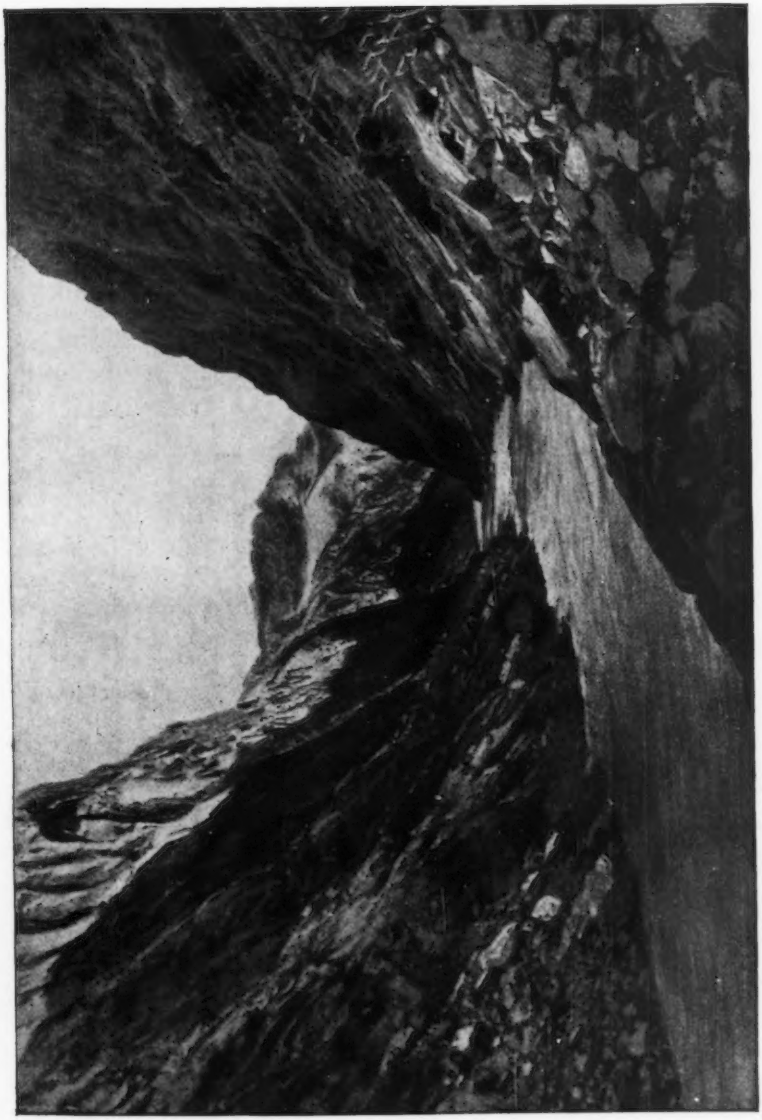
From the mouth of the Kanab Wash for 20 miles down is perhaps the narrowest and deepest part of the great inner gorge. The lower sandstone and limestone ledges have sunken under the river, and the

marble and upper sandstones have come close into the water. At the bottom the gorge is from 150 to 200 feet wide, and the river runs between vertical walls, but vertical only for about 80 feet up. The walls of this portion of the cañon (and it comes nearer being a true cañon than any other part of the river) rise above the water over 2 000 feet. They have the least slope, the benches are narrow, and the vertical cliffs between the benches higher than in any other section. For 19 miles, however, there is a continuous bench about 30 feet above high water and running almost parallel with the grade of the river. This bench is of solid imperfect marble or limestone, from 50 to 80 feet wide, and its alignment is such that it could be occupied the whole distance by tunneling some of the short, sharp points (Plate XXXV). Photos. Nos. 597 to 612 show its general character, and also the detailed work necessary for its occupancy.

In the next section of 54½ miles, which reaches to the lower granite gorge, there are several points worthy of note. The large proportion of "hillside slopes," over 37 miles (see Photos. Nos. 625 to 655—59 and 60), and also the large amount of "heavy talus slopes," nearly 15 miles. In fact, it seems a misnomer to call this section, except at a few points, a cañon at all. It is a valley broad and in some places flat, with gently sloping hills. In this section occurs that portion of the cañon so broken up and rended by volcanic action. Here also are found bold points of basalt which in a few places will require very heavy work.

The lower granite gorge, commencing about 2 miles above Diamond Creek, is 39 miles in length. This second gorge is almost of the same form and proportion as the great granite gorge at the head of the cañon, except that the granite, which is gray and black, with patches of red, rises higher than in the gorge above. Its walls slope from the water at angles varying from 10 to 50 degrees from vertical. It has not, however, the regular slope of the upper gorge. In its first half the buttresses of massive rock that jut out over the slopes into the river are bolder and more numerous, the granite is more compact and solid, and is cut through by more side cañons and washes. The second half is, as in the gorge above, shattered and broken, and has much flatter slopes. This gorge is shown in Photos. Nos. 661 to 732, inclusive.

In Photo. No. 710 is seen one of the most formidable points of granite on the river. The cañon is very narrow; the wall is vertical for 500 to 600 feet above the water. It is on a slight curve and long bend of the



river, and there seems no other way of rounding this point except by half tunneling. The rock is very compact and solid, and well adapted for such work. In the whole route, as shown by the preliminary survey, there will not be required more than one-half mile of this half tunnel work.

From the end of the granite to the Grand Wash cliffs the cañon is but a repetition of the lower end of Marble Cañon. The lower 100 or 200 feet of "the walls" consist of great slopes of the softer limestones, covered with loose débris. For miles these slopes extend to a height of 500 to 800 feet. In this section of the cañon are numerous streams of clear water coming in from immense springs in every direction and at different heights above the river. This water is strongly impregnated with carbonate of lime, and in running over the cliffs and slopes has left deposits of lime which in places stand up 100 feet high.

The following table gives the condensed statement of the classification of the Grand Cañon.

The distance through this cañon is 217.150 miles.

CONDENSED TABLE OF CLASSIFICATION—GRAND CAÑON.

MILES.	GENERAL CHARACTER OF WORK.	Photographs illustrating each class of work.
51.050	Hill side slopes, E. & L. R. & S. R.	Nos. 375, 553
43.750	Heavy and light talus slopes, L. & S. R.	Nos. 456, 735
11.600	Cliff bench work—sandstone	Nos. 542, 555
3.—	High cliffs and bluffs "	Nos. 393, 409
1.250	Solid rock slopes "	
.200	Heavy embankment in river	No. 414
19.000	Marble bench work	Nos. 602, 608
85.925	Sloping granite walls	Nos. 420, 469
.875	Tunnels (6).	
.500	Vertical cliff and half tunnel.	

(6, 7, 8, 9 and 10) LOWER OR VALLEY DIVISION.

At the Grand Wash cliffs the whole country drops, and has been washed away by the drainage of the prehistoric lake above to a much lower level, and the cañon ends in an open though hilly valley, with gentle, easy slopes compared with those the line has passed over. While the general character of the sections which have been numbered 6, 7, 8, 9 and 10, and which will be considered together, is that of an open valley, in places the granite rises up on either side of the river and forms a number of short "cañons," notably the Hualapai, Boulder, Black and Mojave. Generally the walls of these cañons are low and flat, and the rock much broken up.

In two points, a couple of miles each, at the head of the Boulder and Black cañons the walls stand vertically from the water's edge, and necessitate several short tunnels in order not to obstruct the river, for it must be borne in mind that the Colorado is a navigable stream for large steamboats from its mouth to the Rio Virgin.

Very much the larger portion of the line from the Grand Wash to the Gulf is over open flat lands—and low bluffs and slopes of "gravel-wash"—many miles through the Colorado, Mojave and Chemhuevis valleys being perfectly level bottom lands of earth. (See Photos. 745 to 905, inclusive.)

The following general table gives the results of the whole survey in condensed form: (See next page.)

In order to grasp more clearly the question of practicability of a railway route through the great cañons and gorges of the Colorado River, the following comparison of the results of the survey is given in percentages, the distances and percentages being in round numbers.

The Cañon Division, from Grand Junction to the end of the Grand Cañon. Distance, 630 miles. Of this—

62½ per cent. is comparatively light work, earth, loose rock and talus slopes of loose and solid rock.

35½ per cent. is heavy, solid rock, and cliff bench work and sloping granite walls.

2 per cent. is tunneling and half tunneling.

Or, if the shorter line in Glen Cañon is used, this tunneling increases to 3 per cent.

The Lower or Valley Division. Distance, 408 miles. Of this—

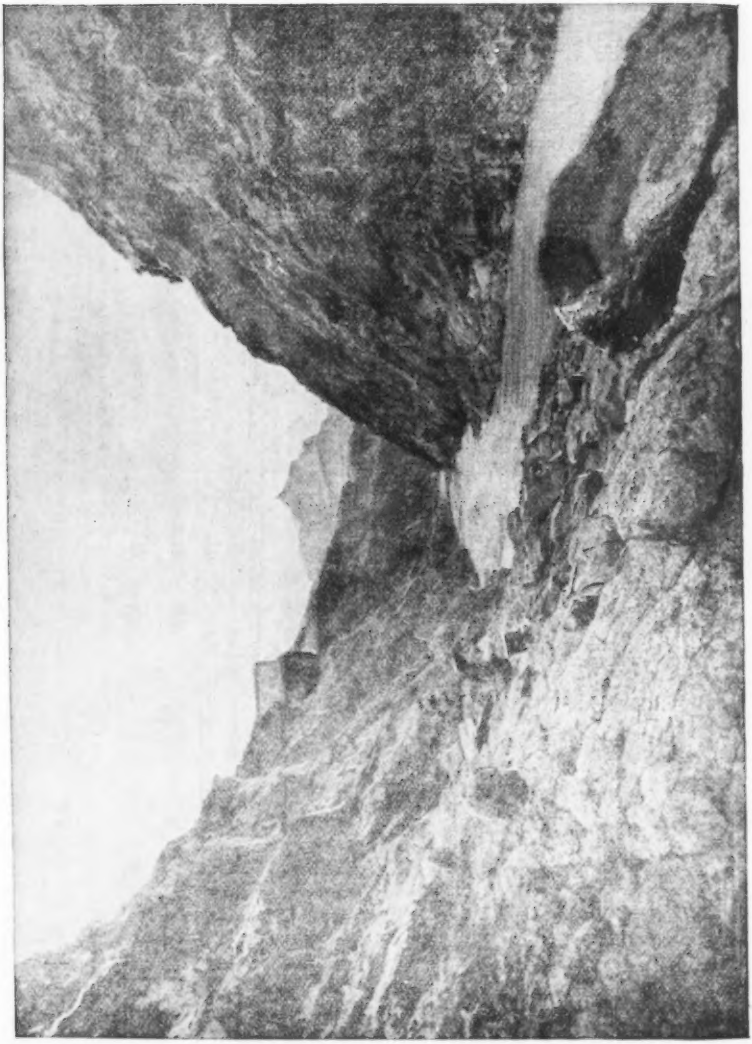
75 per cent. is earth, and gravel work.

24½ per cent. is solid rock work.

0½ per cent. is tunneling.

"C." Methods of Handling such a Work.

It is in no way connected with the purposes of this paper, nor is it considered necessary to here insert the writer's estimate of the first cost of constructing such a railway as was contemplated in this survey. With the tables and descriptions given, and the full series of photographs, any one familiar with such work can very readily form an approximate estimate. A few facts that would bear particularly upon this first cost will be of interest to engineers. Through a gorge of such length it has been considered that work could only be carried on from



General Table of Classification in Miles.

Divisions.	Level bottoms—earth and gravel slopes—"earthwork."	Hillside slopes, R. and L. R.	Rough talus slopes of L. R. and S. R., and boulders.	Smooth, solid rock slopes.	Cliff bench work—sandstone and marble.	High cliff work—not vertical.	Sloping and heavy granite walls.	Heavy through rock cuts.	Heavy embankment in river.	Rock bluffs in lower cañons.	Tunnels.	High vertical cliffs and half tunnels.	Totals.
Grand River	36.323	19.273	61.035	6.206	.....	.....	13.040	.....	.....	.....	4.110	.....	139.987
Cataract and Narrow Cañons	11.543	5.436	14.545	2.557	19.110	.....	.....	.....	.739	.....	.284	.....	54.214
Glen Cañon	57.270	10.928	55.926	21.284	.....	.....	.....	.501	6.553	.....	4.118	.....	156.580
Marble Cañon	.500	.....	26.510	.....	32.250	.....	.....	.125	.750	.....	2.375	.....	62.510
Grand Cañon	.....	51.050	43.750	1.250	30.600	3.000	85.925	.....	.200	.....	.875	.500	217.150
To Rio Virgin	26.500	.....	.....	.....	.....	.....	.....	.....	.250	10.750	.....	.....	37.500
To Las Vegas Wash	16.500	.....	.....	.....	.....	.....	.....	.....	.....	11.500	.500	.....	28.500
To Needles	67.750	.....	.....	.....	.....	.....	.....	.....	.....	27.750	1.000	.....	96.500
To end of Survey, near Gulf	197.255	.....	.....	.....	.....	.....	.....	.....	.....	47.500	.....	.....	244.755
Totals	413.641	86.687	201.766	31.297	81.960	3.000	98.965	.626	8.492	97.500	13.262	.500	1 037.696
If the long tunnel line in Glen Cañon is used = Totals.	403.947	86.232	191.359	27.825	81.960	3.000	98.965	.570	7.356	97.500	20.002	.500	1 019.216

the two ends, thus increasing very much the time and cost of construction. The line would start from the town of Grand Junction, Colo., situated in a large and rich agricultural valley.

At this point it would connect with the Denver and Rio Grande Railway and the Colorado Midland, and all their railroad connections from the East, and the Rio Grande Western Railroad from Salt Lake City and the West. By its recently built line, the Rio Grande Western road comes down to the Grand River at a point about 22 miles below Grand Junction, and practically follows the river for a distance of 30 miles farther. Seventy-five and 100 miles down the river, are well settled agricultural valleys connected by ordinary wagon roads with Grand Junction and the railroad.

Going now for the purposes of transportation to the Green River, by the building of an easy wagon road of about 5 miles, connection can be made with the town of Blake on the Western Railroad, and a point on the Green River below the lowest rapid. From there to the head of the Colorado, a distance of 115 miles, supplies and materials can be transported by means of steam launches and flatboats. From a depot established on the flat at the head of the Colorado, these supplies can be carried at first by "jack-train," and afterward, as the work progresses, by wagon, up the Grand to meet those from above, and down the Colorado to meet those from Dandy Crossing, 54 miles below. The opening of these "jack-trails" could be accomplished with little expense, not only in this section, but through a large part of the Cañon Division.

Crescent Creek and Dandy Crossing are connected with the railroad by good, though sandy, wagon roads, 120 miles in length. From Dandy Crossing there is already a good trail, 20 miles, down to the placer mines. Supplies can be also carried down on flatboats through parts of Glen Cañon, as heavy boilers and machinery have so been carried as far as Tickaboo. There are also wagon roads down to the river at a number of places in Glen Cañon, such as at Smith Brothers', Hall's Ferry and other placer mines.

At Lee's Ferry the river is connected by good wagon road—90 miles—with Kanab, Utah, on the north, and Flagstaff, Arizona—190 miles—on the Atlantic and Pacific Railroad, on the south. Supplies can be carried up river from Lee's Ferry for some distance by steam launch and down into Marble Cañon by jack-trail. A wagon road now exists to the brink of Marble Cañon, about 40 miles below its head, at a point oppo-

site Point Retreat, and an easy trail can be cheaply made down to the river. Such a trail already reaches the river by way of the Nan-Co-Weap.

At the head of the Grand Cañon there is a wagon road to the top from the railroad at Flagstaff, and a trail down to the river, just below the Little Colorado. This with some expense could be so improved as to deliver supplies for the lower end of Marble and upper end of Grand Cañon. Through the Grand Cañon, on account of its depth, there exist as yet but few ways of reaching the river. There is a good trail down Kanab Wash—only requiring some improvement to be used for supplying the whole section for 35 miles above.

At the mouth of Diamond Creek there is a good wagon road from the river to the town of Peach Springs, 24½ miles distant, on the Atlantic and Pacific Railroad. Diamond Creek is 53 miles from the mouth of the Grand Cañon. Below the cañon is the old road and ferry at the Grand Wash, and the roads and ferries at Scanlon's and the Rio Virgin connecting both with the Atlantic and Pacific Railroad and the rich country around St. George and St. Thomas and that of southwestern Utah.

Thus it will be seen that in the Cañon Division work could be carried on simultaneously at at least forty different points, while below the Rio Virgin supplies and material could be delivered at any point by the steamboats now running on the river. The only additional expense in construction would be the extra cost of transportation and preparing trails in the Cañon Division, while on the other hand there are a number of reasons why the cost of construction would be much reduced.

For the first three items in the general table of quantities no new factor of either increase or decrease of expense would enter. Of the 403 miles noted as "earthwork," the greater part is light plow and scraper work. The 86 miles of "hillside slopes" and 191 miles of "talus slopes" would be very largely side hill cut with no haul for waste.

The next seven items in the table consist chiefly of solid rockwork. So much of this—including the 99 miles of granite walls—stands in slopes approaching 40 degrees from vertical, that it would be the cheapest kind of rockwork. While from the nature of the slopes the road-bed would be almost wholly in excavation, only a minimum cross-section would be necessary and the waste thrown directly into the river, thus reducing to a minimum the handling of the rock, and the number of men and animals required on the work, so that this large proportion of solid rockwork would not nearly approach the cost of such an amount

in a level or settled country. The heavy embankments in the river would be very expensive to build. The tunnel-work would only be affected in cost—by the inaccessibility of the country. And the total amount—20 miles—when is considered the large amount of curvature and distance (42 miles) saved, is not far in excess of such work on a number of already constructed roads.

It is the opinion of the writer that one feature of modern machinery might be used with great economy on this rockwork and tunneling—that is, electrical drills—by employing the rapid current, falls and cataracts of the river to generate the electricity.

No estimate of the cost of such a plant has been made; but it is believed that with current wheels and movable power stations great saving would result not only in the work itself, but very largely in the reducing of the number of men employed and the transportation of material and supplies for their subsistence.

"D." The Nature of the Line Itself.

First.—The Grades.—Starting from the town of Grand Junction it is possible to build a railway with a continuous down grade the whole length of the line to the Gulf of California, and to have a returning grade with a maximum not exceeding 12 feet per mile, except for a distance of 20 miles, and then it need not exceed 20 feet. It would be neither economical nor advisable to construct such a line. From the surveys made it is believed that in no place would it be necessary to use a grade in either direction to exceed one-half of 1 per cent. or 26.4 feet per mile. A careful location may make it advisable to increase this maximum.

The following table gives the average fall of the river through the various sections. The distances are by the river and not by the survey: (See next page.)

Second.—The Alignment.—The Grand and Colorado Rivers are large streams, flowing, as regards their detail, in long sweeps and gentle curves. This is well shown in the series of photographs. Reference has already been made to the sharper bends requiring tunnels. From the surveys made it is believed that an economical line can be located with curves not to exceed 10 degrees, or, in other words, with a radius of 573 feet.

Third.—The Nature of the Road-bed and Maintenance of the Permanent Way.—Along those portions of the route where it would be necessary to construct the road-bed upon low, flat bottom lands, the river is broad and

PLATE XXXV.
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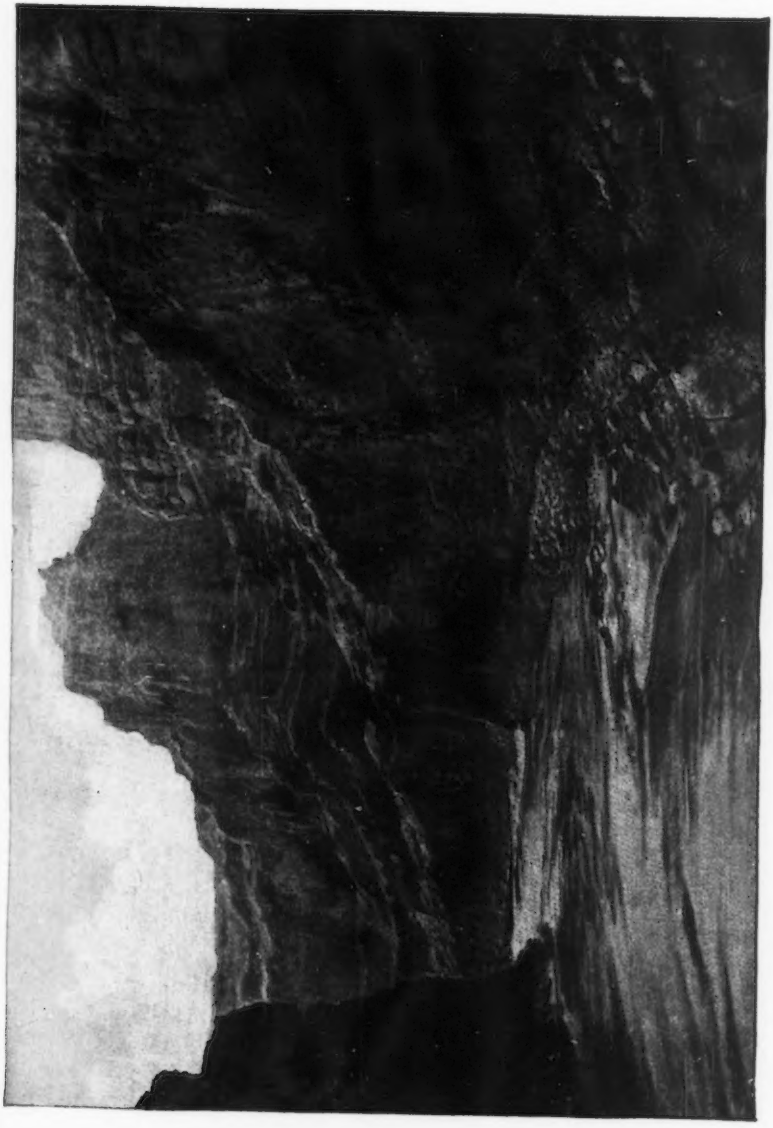
STANTON ON CANONS OF THE COLORADO.



shallow and its fall is very light. These flats are above all ordinary high water; the line can be securely built across them, and rip-rap and material for slope wall protection can be easily and cheaply procured. In the same section, as explained above, where it is necessary to build some miles of the road-bed in the river, under the cliffs, the same facts exist, and the difference between low and high water is a minimum. These embankments would be built almost entirely of solid rock. Along the solid rock benches and sloping walls of sandstone, marble and granite the road-bed would be almost entirely in excavation. One notable fact is the almost entire absence of great slopes of loose rock or slides, which are generally so difficult and dangerous to handle. It is almost universally the case, as is clearly shown by the photographs, that these so-called talus slopes are composed of horizontally statified rock in place, covered with a thin layer of loose débris, so that the road-bed in almost its whole extent through the Cañon Division would be built on solid and durable foundations.

Divisions of the Grand and Colorado Rivers.	Distances in miles.	Total fall in feet.	Average fall per mile.
Grand Junction to head of Colorado	162.4	650	4.00
Cataract and Narrow Cañons	55.	355	6.45
Glen Cañon	150.	325	2.17
Marble Cañon	65.2	510	7.82
Grand Cañon to the Granite	18.2	110	6.04
" " to the Granite Falls	10.	210	21.00
" " to Powell's Plateau	26.4	320	12.13
" " around Powell's Plateau	10.8	100	9.26
" " to head of Kanab Division	4.8	50	10.42
" " Main Kanab and Uin-Karet Divisions	65.2	310	4.75
" " Sheavwits Division to Granite	12.	70	5.83
" " to Diamond Creek	18.	210	11.66
" " in Granite below Diamond Creek	7.2	25	3.47
" " " " " "	10.8	100	9.26
" " to Grand Wash	35.	175	5.00
From Grand Wash to Las Vegas Wash	68.	300	4.41
Total to Las Vegas Wash	719.	3 820	5.31
From Las Vegas Wash to Gulf or end of Survey*	425.	700	1.64
Grand total	1 144.	4 520	4.00

* This last distance does not take in all the many windings among the Sand Islands in the lower part of the river.

The features peculiar to this route and affecting the maintenance of the permanent way, remain to be considered. They are the drainage across the road-bed and the possible effect of loose material from the cliffs above. During the survey, as stated above, notes were taken of all

waterways from 10 feet upward, and estimates made of all other drainage required. As might be expected from the formation of the country, many side streams and cañons enter the main gorge. Many of these a little way back from the main chasm are from 1 to 3 miles wide on the top; but they enter the Colorado through the lower and harder strata of compact sandstone, marble and granite, and through narrow channels that can be spanned by from 50 to 100 foot bridges. These are clearly shown by many of the photographs taken. There are some exceptions to this class where the mouths of the side gorges have been washed out into wide flats. Such are the Nan-Co-Weap and Kwagunt branches of the Marble Cañon. These do not present any more difficulties than the crossing of any wide water course not in such a cañon. Of the smaller waterways the granite and marble give solid abutments on either side, and the channels are deep and narrow.

There is one feature of the drainage peculiar to such cañon-work; that is the small streams that come over the tops of the cliffs. Where the cañon is wider and the talus slopes exist at the foot of the cliffs, these small streams have worn out basins back, next to the cliff, into which they fall, and from which they can be carried under the road-bed in the natural channels that now exist. In other portions, where the road-bed would be cut along the benches, these small streams (which only flow during storms) and the débris brought down with them can be carried over the road-bed by a simple device of overhead drains. Taken as a whole the drainage does not present any insurmountable difficulties or any very difficult problems not found upon other mountain roads.

The question of falling rock and loose material from above is not different here from what obtains on hundreds of miles of operated railroads through the Rocky Mountain region. The immense width of the cañon on top prevents the great mass of rock loosened from above by storms reaching the inner or lower gorge in a way to do any damage. The lowest gorge is of a harder material and not so easily affected.

One feature largely affecting the maintenance of way, and also the traffic of such a road, is the almost entire absence of snow and hard freezing from so large a portion of the line in the great cañons. During the winter of 1889–90, the expedition experienced only two hours of snow storm at the level of the river, while the whole upper plateau was covered with from 3 to 6 feet of snow. It may be remembered that the winter of 1889–90 was one in which the transcontinental railroads through the

Western mountains suffered more from snow blockades than they had for years previous.

A brief abstract from the register of the thermometer from November 28th, 1889, to May 1st, 1890, may be of interest.

Sections of the Route.	Max.	Min.	Average.		
			6 A.M.	Noon.	6 P.M.
	Degrees	Degrees	Degrees	Degrees	Degrees
From Green River to Dandy Crossing, November 28th to December 10th, 1889	65	10	34½	52½	45½
Dandy Crossing to Lee's Ferry and to middle of Marble Cañon, Dec. 10th to Dec. 31st, 1889	66	30	39½	54½	47½
Month of January, 1890, in lower Marble and Grand Cañons	68	24	37¾	48	43
In Grand Cañon, Feb. 1st to March 17th, 1890	82	29	47	61½	55
End of Grand Cañon to Fort Mojave, March 17th to March 23d, 1890	76	42	52	66	61
Fort Mojave, The Needles, Yuma and the Gulf, March 23d to April 30th, 1890	93	40	52	83	75

Taking, then, the whole line into consideration, when once properly built it would not only not be highly expensive to maintain, but in many points would be far below the average of mountain railways, and in the matter of winter transportation would have advantages over any line crossing the country from the Rocky Mountains to the Pacific Coast. The scarcity of water through this same section that so affects the present transcontinental roads would be entirely done away with, the supply from the river being the best possible when allowed a little time for the settlement of the sand.

Second.—The Advisability of such a Railway. Through Passenger and Freight Business.

In the investigation of that part of the subject under consideration—the advisability of opening a new line of transportation across the western half of the continent—the engineer is called upon to go beyond the limit of what is ordinarily called the science of engineering and to answer the question, Will it pay? There are, however, a number of elements entering into this question which are outside the scope of this paper; but the more limited inquiry of what business would such a railway find to do, is one entirely proper to be answered by the engineer who examines the country for the purpose of gathering all possible information bearing upon the final success or failure of the enterprise.

One important item must be first made clear. It will be remembered that the original object in the projection of this railway was to connect the coal fields of Colorado with the Pacific Coast. These very extensive coal fields are already connected with Grand Junction by several railroads. The scarcity of cheap fuel on the Pacific Coast is well known. The much larger proportion of the fuel used there is imported from foreign countries. The question first proposed was how to connect these two distant points with each other, so as to cheaply and profitably transport the abundant fuel of the one to the extensive fuel market of the other. The nature and extent of this coal trade will be considered further on.

For the purposes of such a business as the transportation of large quantities of coal, coke and other fuel, it was thought best to reach as quickly as possible tide-water at the head of the Gulf of California. The great difficulty and danger of navigating this gulf, and the almost impossibility of securing a safe harbor at its northern end, puts this as a terminus out of the question.

Without further explanation, it will be considered that the road would be built down the river to the neighborhood of Yuma, and then, crossing the Sierra Nevadas at an elevation of about 2 600 feet, terminate at the extensive land locked harbor of San Diego.

It was also first expected to secure all fuel for the Pacific Coast in Colorado. Other coal fields, however, exist many miles nearer that market, that would be reached by and have all the advantages of this low grade means of transportation. It will therefore be considered that the road for which it will now be proper to look up its present and future business consists of a line from Grand Junction to the port of San Diego, with branch lines to the various coal fields, and especially one up the Rio Virgin to the extensive coal deposits of southwestern Utah.

First.—Passenger Traffic.—It will be conceded that any road built across our Western country would get a share of the passenger travel between the East and the West. (This may be also said of the through freight traffic.) As to the passenger business of this proposed road being in excess of all other lines across the continent, one or two short quotations bearing upon this subject will be sufficient: "Those who have long and carefully studied the Grand Cañon of the Colorado, do not hesitate for a moment to pronounce it by far the most sublime of all earthly spectacles. If its sublimity consisted only in its dimensions, it

could be sufficiently set forth in a single sentence. There are in the world valleys that are longer and a few which are deeper; there are valleys flanked by summits loftier than the palisades of the Kaibabs, still the Grand Cañon is the sublimest thing on earth. It is so not by virtue of its magnitude, but by virtue of the whole, its ensemble."

"To the conception of its vast proportions must be added some notion of its intricate plan, the nobility of its architecture, its colossal buttes, its wealth of ornamentation, the splendor of colors, and its wonderful atmosphere. All of these attributes combine to produce a whole which at first burdens and at length overpowers."

What is likely, then, to be the attractiveness of such a route for passenger travel? Remembering that this line, passing through this wonder of the world, would forever have a monopoly of such travel—since no other line could parallel it—it is believed that the passenger travel alone would be sufficient to pay interest on a very large extra cost of construction.

Second.—Freight Traffic.—More and more every year the question of time enters into the transportation of through freight from East to West and from West to East. At no distant day the consideration of how to attain quicker and cheaper transportation of through freight will be one of vital importance to all the transcontinental roads. It is the opinion of the writer that the solution of this question lies in the railway of the future—the railway of lighter grades, lighter curves, lighter rolling stock, lighter trains, more of them and quicker time. What a field of investigation this thought opens up! Even now the transcontinental roads are considering what effect the opening of the Nicaragua Canal will have on their future business in cost of carrying through freight.

What, then, would be the advantages of a railway line, which over the very roughest portion of the section traversed by all these roads would have 1 000 miles of its distance with grades not to exceed one-half of one per cent. or 26.40 feet per mile? And what advantage would it also have for the whole year's business, when this 1 000 miles, the very worst for winter travel, would be almost entirely free from frost and snow? Such a line would of course cross the Sierra Nevadas, but so far south and so low that it would have but little to fear in winter.

It is here only estimated for a line to Grand Junction and across the Rocky Mountains by existing roads. The crossing of the Continental

Divide has never yet been accomplished so as to secure the best advantages. This cañon road carried up the Grand River through Middle Park and across the range on a line located by the writer more than ten years ago, it is believed would secure many advantages and reduce the rigors of winter travel and transportation to a minimum.

The following profile (Plate XXXVI) on a reduced scale and those of existing roads, taken from their published statements, together with the table of comparative distances, illustrate this part of the subject.

Railroads from Denver to— (Distances in Miles.)	San Diego.	San Francisco.
Union and Central Pacific	2 035	1 516
D. and R. G. and Central Pacific	2 185	1 666
Atchison, Topeka and Santa Fé	1 638	1 724
Denver, Colorado Cañon and Pacific Route	1 472	1 981

Distances from Chicago to—	San Diego.	San Francisco.
Northwestern, Union and Central Pacific	2 933	2 419
C. B. and Q., D. and R. G. and " "	3 208	2 694
Atchison, Topeka and Santa Fé	2 347	2 577
Southern Pacific and "	2 650	2 805
Northern Pacific	3 847	3 238
Denver, Colorado Cañon and Pacific Route	2 500	3 009

Local Business.

Woe to the railroad that has nothing but through passenger and freight business to depend upon! In order to understand the possibilities of the immediate local freight business, and what may be reasonably expected as the future development of such a trade, it will be necessary to rapidly glance at the whole extent of country along the route. This becomes more necessary when it is remembered that this whole section has generally been considered totally barren of any such possibilities.

The initial point of this proposed railway is at the town of Grand Junction, Colorado, the largest and most prosperous agricultural center in the western part of the State. Mesa County, in which it is situated, and which at this point contains a valley of nearly 500 000 acres of the finest agricultural and fruit land, has also varied and extensive mineral resources. Its coal fields are considered inexhaustible. Many large bodies of coal have been discovered and developed. Some extensive deposits lie in close proximity to this proposed route. Many of the

PLATE XXXVI.
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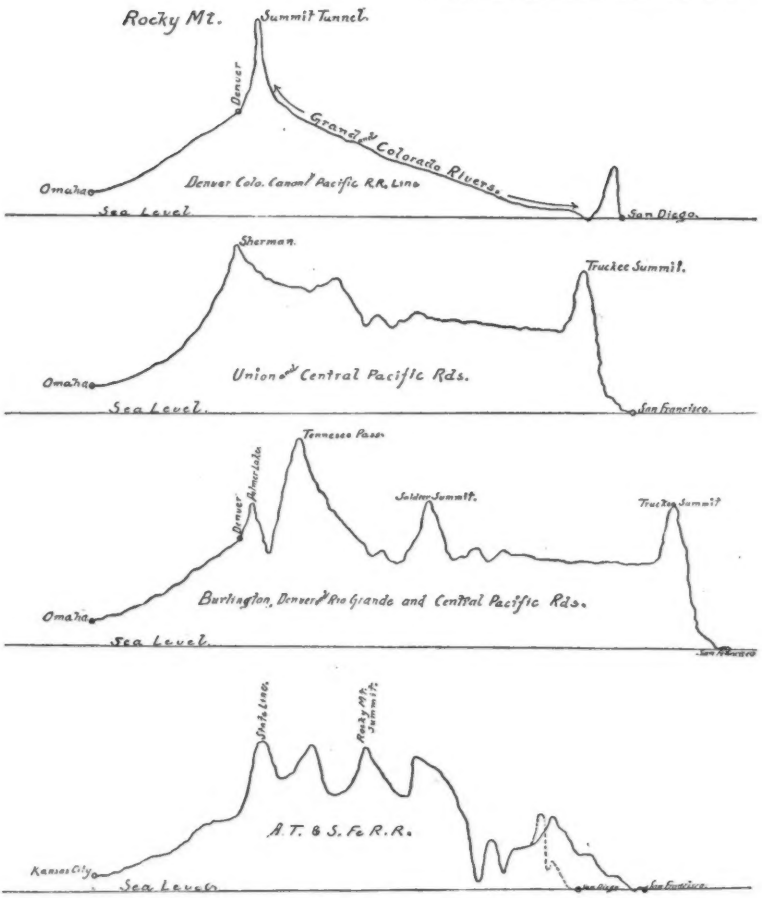
STANTON ON CANONS OF THE COLORADO.



extensive anthracite coking and steam coal fields of western Colorado are connected with Grand Junction by rail. This point is practically the western terminus of all the railroads coming into Denver from the East. The section of country around Grand Junction is rapidly settling up. Following the Grand River, 75 to 80 miles, is the Little Castle Valley. This, with the Little Grand and other valleys along this river, form a large tract of rich, though only partially developed, agricultural land. Anthracite coal has been discovered within 7 miles of Richardson, on the Grand, and other large deposits of coal have been located at various points. The present cattle interest in this section is considerable. It is estimated that there are in the valleys and on the mountain ranges tributary to the Grand and Colorado rivers 1 500 000 head of cattle, between this point and the Kaibab Mountains.

The line from here to Dandy Crossing, through the lower part of the Grand River and through Cataract and Narrow cañons, does not encounter any productive land near the river. Back at the heads of many of the side cañons are large tracts of grazing land, many of them occupied by herds of cattle.

From Dandy Crossing to Lee's Ferry, a distance of 150 miles, the gold placer deposits are almost continuous the whole way. In past ages while the river was cutting its way down through the red sandstone of Glen Cañon, there were deposited on the successive levels of the stream vast beds of fine and coarse gravel, into which has settled great quantities of fine gold dust. Whence this gold has come is a question on which there is a great difference of opinion; this is of but little importance to the present investigation. These beds of placer gravel are found all along this whole extent of 150 miles, on the benches of the cañons, at various heights, some being 100 feet and more above the level of the water, while the larger amount of the deposit is from 10 to 50 feet above low water, with very extensive bars in the bed of the river, which are overflowed during high water.

From personal examinations the writer considers these gold deposits not only very extensive, but very rich and valuable. On account of their situation, so much above the level of the stream, and the fact that through this section the river has so little fall, these bars can only be worked by using more machinery and much more extensive plants than are usually necessary in such cases. This is the reason why these bars have not been more extensively worked up to this time. With a

railroad through this cañon these mines would be largely and profitably handled. The transportation of machinery, lumber, mining supplies, provisions and all the traffic incident to such a population as would be engaged in even placer mining, extending as it would along the river for 150 miles, could not but create quite a local business through this section. From some measurements and estimates made on particular bars, it would be difficult to wash out these deposits within the next 100 years.

Through this section of Glen Cañon at various distances from the river many other valuable mineral deposits have been discovered. These are as yet undeveloped. The mineral and coal deposits of the Henry Mountains are within 25 miles of the river. Coal has been found at several other points from 6 to 20 miles back in the side cañons above Lee's Ferry. In the neighborhood of the San Juan and Escalante rivers are well defined deposits of petroleum.

By a line up the San Juan River it is possible to make connection with the rich Montezuma Valley, and the coal and other mineral deposits of that part of Colorado. At Lee's Ferry connection is made by wagon road with the agricultural and grazing country of northern Arizona and southern Utah. This is largely subject to the necessities of irrigation, yet great quantities of oats and barley are successfully raised without irrigation. It is considered that all the cattle, sheep, wool and other products of that section—and they are of no mean account—would be taken to the river for a means of transportation rather than driven to the railroads running north. From Lee's Ferry, for some 50 miles down through Marble Cañon, there would not be expected any local business, except perhaps the shipment of building stone. The great variety of building stones through all the cañons, sandstones, limestones, marbles and granites, would undoubtedly create some considerable business for the road. The fact that the largest building being erected to-day in the City of Denver is being built of the same stone that forms the upper walls of the Grand Cañon, and that this stone, shipped from Flagstaff, Arizona, is carried as far east as Kansas City and Chicago, shows that a traffic for this road in building stones is not beyond the probabilities.

Some 15 miles above the head of the Grand Cañon, begins the great mineral belt that extends all the way through and on either side of this great chasm. In the lower end of Marble Cañon, as the sandstones

and limestones rise and recede from the river, there come up other strata of limestone, sandstone and quartzite which lie above the granite, and between these are extensive veins of mineralized matter. At the head of the Grand Cañon, above the granite, are immense veins, mostly horizonal, of iron ore and silver, lead and copper deposits; and at one point a large bed of roofing slate has been located. As the granite rises quartz veins of various sizes are seen in every direction and running at every angle, while the horizontal veins of mineralized matter—silver, lead, copper and iron—above the granite extend all the way to the Grand Wash cliffs.

Through the whole cañon the writer saw and took samples from numerous and extensive croppings of silver, lead, copper and iron ores, and deposits of salt and mineral paints. While it would not be proper to state positively—from so short and rapid an examination—that these veins and deposits are rich in precious metals, yet with such extensive fields and such fine croppings it is not unreasonable to conclude that much real value does exist. The mineral lies from 100 to 1 000 feet above the river, and consequently from 4 000 to 5 000 feet below the plateau country. While it would be a very easy matter to bring this ore down to the river to a means of transportation, it is practically impossible to take it up to the plateau above. Here again, then, with a railroad through the cañon, would be developed a large local business not only in the transportation of ores out, but of machinery, supplies, provisions, etc., in. One other item through the Cañon Division would furnish some little, at least, local business—the timber that covers the plateaus and Kaibab Mountains. As the demand for tie timber grows more and more every year, this timber, though it is far above the river, can and will be brought down, rather than be carried up to a means of transportation.

Below the great cañons is found an entirely different country. Taken as a whole it is a broad and open valley. At the mouth of the Rio Virgin connection is made with the old settled and richly cultivated country of southwestern Utah. Along the valley of the Rio Virgin and its tributaries are rich agricultural lands. At the mouth of the river are raised to-day, besides grain, all the varieties of European and native grapes, peaches, plums, pears and nectarines, limes, pomegranates, figs and almonds.

The valley of the Colorado from the Virgin to Yuma must be considered under two heads:

1st. As a mineral country.

2d. As an agricultural country.

About 6 to 18 miles up the Rio Virgin are located great mountains of rock salt, much of it pure, but the greater part of a pinkish purple color. The lower valley of the Colorado is flanked on either side by ranges of hills and mountains. These ranges are cut in every direction by mineral veins. Many of them that extend from the tops of the mountains down to level of the valley can be seen for miles. This country, as a mineral section, has been known for years. The minerals are gold, silver, copper and lead. The old mining camps in Gold Basin, Lost Basin and El Dorado Cañon are well known. The mines in El Dorado have been worked, more or less continuously, since 1861, and the gold and siver mill at that point since 1864. At some points the ore is very rich. The greater quantity, however, is of a lower grade, and will not bear the cost of mining and milling, on account of the scarcity and high price of fuel. At El Dorado, coal brought from Galup, New Mexico, by rail and up the river by steamboat, costs $14 per ton. With a railroad through this valley that could deliver cheap fuel, hundreds of developed mines, that now stand idle, could and would be profitably worked, and hundreds of others would be opened and developed.

In the next place, with a railroad built, and only a portion of the possible mineral development and operations under way, hundreds and thousands of acres of the rich agricultural lands of the Colorado, Mojave and other valleys of the Colorado River and its tributaries would be under cultivation, for there would be a ready and profitable market close at hand. These valleys would be cultivated not only in the ordinary farm products, but in a great variety of semi-tropical fruits. At the present time some of the accessible tributaries of this river are being set out in groves of oranges and lemons.

One more item of immediate and future business remains to be considered—the coal trade. With the great advantages of this proposed road as to distance, winter travel, and especially grades, the better classes of fuel, such as anthracite coal and coke, could be profitably carried from Colorado to the Pacific coast. The greater quantity of fuel, however, would be taken from nearer points, notably from the coal fields of southwestern Utah.

This fuel, transported at the most economical rates, over a down grade road, would first be delivered to the mining and milling operations all along the Colorado River. At The Needles it would reach the Atlantic and Pacific (the Santa Fé) system of railroads, for their own use, and for transportation into California at a much lower price than they can transport fuel from New Mexico. At Yuma the same would be the case with the Southern Pacific Company, for their own use, and for shipment both east and west over their lines.

At San Diego the whole of Southern California could be supplied with fuel, which it now so much needs, and from there transported by water as far north at least as San Francisco.

The following tables give the coal brought to the various ports of California in 1889 and first six months of 1890:

COAL RECEIVED AT SAN FRANCISCO.

FROM WHERE BROUGHT.	Year of 1889. Tons.	First 6 mos. 1890. Tons.
Puget Sound	372 514	195 375
Oregon	49 500	30 330
Mount Diabalo, California	38 100	13 200
Eastern, New York and Baltimore	18 950	22 197
British Columbia	383 906	179 808
English, Scotch and Welsh	45 617	13 372
Japan	1 340	4 850
Australia	303 285	84 543
Total	1 213 212	543 675

COAL RECEIVED AT SAN DIEGO.

FROM WHERE BROUGHT.	Year of 1889. Tons.	First 6 mos. 1890. Tons.
Australia	45 780	18 115
British Columbia	10 738	1
Galup, New Mexico	1 859	1 052
Elsinore, California	358	141
Total	58 735	19 309

There was also received at the port of San Pedro, in 1889, a total of 66 760 tons, and during the first six months of 1890 about 30 500 tons.

Even though coal and coke would be delivered by this road, and sold

at from one-half to one-third of its present market price, it is not expected that at once, or even ever, it could take possession of the whole of this trade; yet it is not impossible that with this great difference in price a very large amount of this fuel traffic would very shortly be transferred to the port of San Diego, the terminus of this proposed line. What the future development of this coal trade might be can only be hinted at. With cheap fuel, and an unlimited and certain supply, there is no question but that the consumption of such fuel on the whole Pacific coast would be largely increased, not only in manufacturing, but in many other ways. The opening of the Nicaragua Canal would create a demand farther south, not only for ocean steamer use, but for local purposes. From no other source could this so easily be procured as from this proposed road at the port of San Diego.

In conclusion, from the facts here set forth, it is believed that there is awaiting the opening of such a road as is herein described both a local and through business, in excess of what was ready for many of the lines when built that now are in operation through the western part of the United States, and that a local business would be developed far larger than can ever be expected on some of our great Western railways.

It is hoped that in this description there has not only been shown the entire practicability of the cañons of the Colorado River for railway purposes, both from an economical as well as a purely engineering point of view, but that there has also been some light cast upon the nature and possibilities of a portion of our great Western empire which, to many, has been less known than the heart of Africa.

DISCUSSION.

ALFRED FRANCIS SEARS, M. Am. Soc. C. E.—I have found this paper by Mr. Stanton a most intensely interesting study. It will prove also a much more valuable document to engineers engaged in the location and construction of cañon lines—and there are many such—than at first view may be apparent. As an engineer's story it contains the excitement of heroic adventure; it is a modest account of extraordinary pluck and nerve. When Mr. Stanton's outfit had been wrecked, his leader and two assistants drowned and the entire party exposed to the perils of starvation, an opportunity for retreat to safety with honor presented itself; but this chance was availed of, not for escape, but to refit and

again venture on the perilous voyage down an unknown cañon, simply in the name of duty to the cause of progress and science. Such persistence in the exploration of the Colorado Cañon entitles Mr. Stanton and the assistants who remained with him to the sincere admiration of his professional brethren.

My object in entering on a discussion of this interesting paper is to present some facts from my personal experience that should be of value in works of this character. I think, if I were called on to make a survey of such a stream as is here described, I would take advantage of some of the work I have witnessed in the west branch of the Hudson by the lumbermen who drive that river in the spring. Some of the members of this Society who have lived or hunted in Essex and Warren counties have doubtless seen boats go through the horserace near Johnsburg, a deep, narrow cañon with vertical walls of great height, and have seen the same men pass the rapids above and below that point. I believe I should seek that class of skilled labor at almost any expense if I had to do such work in North America. The experience of men who can shoot rapids in a light canoe is very different from the genius which can carry a heavy boat through such peril; a kind of work with which the river drivers of mountain torrents, and only they, are familiar.

I do not know if my experience is unique, but it has been my fortune, certainly not a common one, to engage in the construction of a line of railroad of which I have been obliged to witness the almost entire demolition by an extraordinary series of cataclysms. It was a line situated in a cañon very similar in character to this described by Mr. Stanton, and we had already graded 125 kilometers and laid track, and were running trains over one hundred and eight of them, when the catastrophe occurred by which there have not been left in all that distance five consecutive kilometers over which so much as a hand car can be moved, save in the flat region between the coast and the precipitous cañon, where some 50 kilometers were repaired and restored to traffic. As teaching the dangers of such a location, the uncertainties of construction and durability of work and the class of accidents to which such work is exposed, I believe some statements from the history of the short lived line in the valley of the Rio Santa of Peru, known as the Chimbote and Huaraz Railway, must be interesting and valuable to the profession. Mr. O. F. Nichols, M. Am. Soc. C. E., who was associated with my predecessor, Mr. Maxwell, in that work, presented a very interesting paper to this Society, to be found at page 365 in Vol. IX of the *Transactions*, illustrating the character of that part of the cañon in his charge. In order to locate the termini of a tunnel it was necessary to triangulate from a slope on the brow of the precipice across the river, his men being let down with ropes near the tunnel approaches. I confess that I suppressed a tremor when three years afterward I looked up from the tunnel at the stations, still noted by staves where Mr. Nichols had operated. That

paper will be an interesting study in connection with this of Mr. Stanton, and gives details of the geology of the region which I omit.

The slope of the Rio Santa by the railroad line permits a gradient of from 1½ to 3½ per cent. between the 50th and 125th K. But from this point up for a few kilos it was found impossible to escape a grade of 5 per 100. From the 50th to the coast the country followed by the river is flat and the current moderate. The upper stream, like all mountain torrents, is a succession of rapids and basins of smooth water. But there are no rifts, *i. e.*, there are no rapids in which rocks of the river bed show themselves. A man falling into the Santa would never be seen again, unless his body were thrown into an eddy on the edge of one of the smooth basins. I have never known a successful attempt at sounding any part of that fearful stream. But Mr. Nichols' paper shows that it was done. Mr. Leffert L. Buck, M. Am. Soc. C. E., put several of the bridges in position, stretching wire cables between abutments for a deck on which to make the erections, falseworks in the river being impracticable.

Mr. Stanton thinks it would be necessary to build the Colorado Cañon road from both ends of the cañon. Unless there are difficulties not yet described I should think such a process unnecessarily tedious and expensive. As a wagon road will be impracticable, a mule trail may certainly be laid up the cañon. In the Rio Santa we had fifteen construction camps between K. 50 and K. 96, all our supplies and building material going in on cargo mules. It is not necessary to maintain a continuous way upon one side of the river. We never crossed the high cliffs that came down vertically into the water if there were a better way on the opposite side of the stream, which we crossed and recrossed on little suspension bridges. I am not certain, but I believe they were designed by Mr. Buck. They were exceedingly simple and proved efficient to the last, their construction being as follows: Five wire ropes of 1 inch diameter were stretched across the river parallel and equidistant (to receive a floor about 4 or 5 feet wide), and anchored securely behind the bridge seat. Across these, at distances of 2 feet, were laid floor timbers 5 inches deep by 4 inches wide, and extending on either end 6 inches beyond the outer cables. The floor boards laid longitudinally were nailed to these timbers. At each end of the bridge and on either side a small iron post of an inch and a half round iron was set securely in the rock, and another cable 4 feet above the floor system was passed through eyes in the top of the posts and anchored about 8 feet behind them. From these last cables round iron suspenders three-fourths of an inch diameter hung by open hooks; the lower end passed through the ends of the floor timbers and were secured by nuts. If I remember correctly, the longest span of this kind was a trifle over 200 feet. These bridges suffered in one singular way. The *serranos*, Indians from the mountains, who drive cattle over them from the hills to the coast for ship-

ment, would, on their return, steal the iron suspenders for home use, and they had the wit to take out alternate rods. We then riveted the lower ends at the nuts and closed the hooks at the upper end.

I ought, before going further, to say that I am separated by the width of the continent from my books and notes of that line and may err in stating details of a work from which I have been absent for thirteen years. I will rely upon Mr. Nichols and Mr. Buck to kindly set me right in such cases.

Once the way is opened along such a cañon by mule trail, sometimes in the cañon along its flats, sometimes on iron bracketed balconies along the faces of cliffs and again over the hills back of the cañon walls, it is not so difficult to carry on the construction. This was done on the Santa by letting men down the precipitous faces with ropes. Seated in "bos'uns' chairs," they drilled and planted rods for step-ladders to go and come. Ropes stretched along the wall for the feet and another 5 feet higher for the hands made rather luxurious pathways along the sheer faces of precipices inaccessible in any other way.

When I read in Mr. Stanton's paper of the flats so favorably placed to receive the line of a railway, I am reminded of similar flats in the valley of the Santa, which after having furnished convenient lodging places for our work, have been wiped out of existence. We had every reason to believe in their permanence—they were of exceedingly hard material, such as in this country we call "hard pan"—an indurated matrix of clay enclosing pebbles of various sizes, from that of a filbert to a large apple. But another evidence of stability seemed to make positive our faith in those little pampas. The old irrigation ditches of the Inca civilization found in the valley by the conquering vagabonds of Pizarro were still intact and demonstrating by their presence a condition of safety in and near their sites which had existed three and a half centuries at the very least; and who could say for how long an age before this discovery?

But in that year of catastrophe, which saw our line destroyed—in 1878—even those old canals which had furnished the controlling datum for establishing our height above the River Santa, were swept from the face of the cañon, and the place which had known them for untold centuries will know them no more. Nor was this destruction produced by inundation. The pampas destroyed were from forty to more than a hundred feet above high water in the Santa, and while they were swept away, the Huayrachiri Camp, at K. 115, not more than 5 feet above the flood, is as secure now as when first erected. The destruction was produced by a flood wave containing a vast amount of earth and rock, moving with great velocity and cutting under the bluff faces of the conglommerate we had thought impregnable.

There was a series of these waves, the formation of only one of which, so far as I know, was witnessed by any human being. Above K. 132 is a

lateral ravine, dry in all seasons save when a shower in the mountains may chance to vent itself by this channel, on which occasions it contains water for an hour or so after the rain is over. It would seem that a slow and continued rain had soaked into the soil overlying some steeply inclined, rocky mountain face, and thus when the mass was saturated and water had settled to the rock, the huge volume of earth had gone down, a vast avalanche, to the bottom of the ravine, where it constituted a dam across the chasm to prevent the escape of waters pouring into it from mountain slopes further up stream. When once the waters thus impounded had risen to the top of the dam and poured over its face, the mass was again swept down and out to the main valley of the Santa. On its way, it gathered new material, and with augmented force rushed across the river, damming it to the height of 40 feet or more. The Santa is a powerful stream and took but little time to rise to its terrible work. This dam must have been 140 feet long across the river at its base and perhaps 400 feet or more on top.

The watchman at La Soledad, Mr. Nichols' old camp, the location of which he has described in the paper already mentioned, heard the fearful warning of the waves' approach, for several minutes before it came in sight, but felt himself entirely safe, as that camp was certainly a hundred feet above the stream. But when he saw this hideous engine of destruction come tearing around the bend a thousand feet off, piled up to immense height in the narrow gorge, its upper volume white as snow, tumbling, foaming, leaping, seething above a tremendous black wall of rushing rocks and water and earth, all struggling together in furious roar and din, tearing at the mountain sides and cutting out great chasms from the world's eternal superstructure, he fled in terror to the hills.

There was a succession of these phenomena, all with attending disaster. At K. 96, in apprehension of danger, I moved a locomotive engine, already cut off from headquarters, to a projecting point of rock crossed by our track and housed it in. When I left the line this engine was inaccessible from any direction save by a rope ladder down the face of the cliff. Where we had blown off the nose of a rocky spur more than 300 feet high to the apex, to form an embankment, in the belief that such enormous fragments could not be moved by any flood, the entire affair has been swept away as completely as if it had been a sand bank.

In passing through the narrow gorges of the cañon, these waves were piled to an immense height, and gathering increased momentum carried forward all the loose rocky material that lay in their way, so that below the Taquilpon Hacienda at, I think, about K. 75, where the river suddenly widens, the bed of the stream, which had been more than 20 feet lower than our road-bed, was when I last saw it, but 5 feet below the rail.

In some lateral ravines, notably the Valley of Taquilpan River, an avalanche, which carried away the bridge, cut out the bed of the stream to a depth of more than 30 feet. Within two weeks this was not only refilled, but the bed of the river was raised 3 or 4 feet above the bottom of the railroad cuts on either bank, *i. e.*, above the level of the bridge floor, being about 10 feet above the bed as it existed when the bridge was built over that little stream. In several places, the mountain has slid down across the railroad to such an extent that where a cut of 40 feet was originally demanded to reach the roadbed, it would now require 140 feet of excavation to uncover the rails.

It need hardly be added that only a traffic of great value and importance can justify the construction of a road in the Colorado Cañon in the manner recommended by Mr. Stanton's paper, *i. e.*, on the flats and low down under the cliffs (page 307, last line of "Third"). I quite agree with the opinion expressed by Mr. Nichols when this paper was first discussed that it seems the better and safer course to resort to a great deal of tunneling. I am not certain if I might not recommend, and indeed in a similar case in the cañon of the Rio Reventezon of Costa Rica I have recommended placing the road upon balconies of wood or iron, bracketed or suspended along the face of cliffs well above all possible danger.

In reference to the use of electricity for working drills I should think Mr. Stanton has no occasion to hesitate. That matter has ceased to be the subject of experiment. The falls of the Willamette, light the City of Portland, Oregon, and furnish power for electric motors. I would go further even; for in that valley, the source of power is such, that electricity generated by water power may and will be used for carrying on the traffic, instead of using steam-producing fuel, which is not easily obtained. The engineer, who is confronted by the problem engaging Mr. Stanton's attention, would gather invaluable knowledge by a visit to the Peruvian road in the valley of the Santa; when he has learned what rain in the hills and a torrent stream can do, he will feel increased confidence to advise and devise.

I am reminded here of an interesting professional experience shortly after my return to the United States and less than two years after the destruction of the Chimbote Railroad. You will have no difficulty in understanding that I approached mountain torrents in a spirit of wholesome caution. I was employed as the umpire or consulting engineer of the Oregonian Railway in the Willamette Valley of Oregon. The contractor who built the road furnished the engineering. The chief of that corps shall be nameless; he is now where contractors cease from troubling and the engineer may rest. I was dissatisfied with the manner of placing the piers in the North and South Santiam rivers, both mountain torrents of great power and volume, and once ventured to say, "I approach streams like these with a great deal of apprehen-

sion." "Oh, no!" replied the chief, "I never fear anything in engineering. I enjoy bridging a river."

When the road was presented for acceptance, I reported against receiving those bridges until they had been proven by the floods of at least one winter. Against this advice, the representative of the Scotch company settled with the contractor, paid for the bridges and the well satisfied gentleman left Oregon for Dundee to secure a contract for completing the line. Before he reached New York both bridges were swept away. Even this was not lesson enough for that unfortunate enterprise. New plans were submitted by a California Bridge Company; and while I approved the bridge plans, I could not approve the piers or location, which should have been changed. But as contractors are "practical men," while engineers, having never used saw nor pickaxe, are only "theorists," I was again overruled. Of course this ended my connection with the company. But every engineer can imagine my intense mortification when, the third winter following their erection, both Santiam bridges were again swept away.

In concluding these remarks upon Mr. Stanton's paper, I wish to refer to the current nature of accidents to which the builders are liable and to some of which also the traffic is exposed after such a line is opened. They are essentially of a single class, the falling of small stones or larger boulders from the slopes in talus, and the falling, let us call it the sloughing off, of masses of material from the faces of cliff where there has been an injudicious use of the explosives.

In the Rio Santa Cañon the early morning sun, by expanding material on the slopes and steep mountain sides, caused small cobble stones to leave their beds and roll down to the river, detaching other stones in their path, so that the early morning traveler was exposed to a dangerous volley unless he were careful to select his time before sunrise, or, an hour or two after the heat had become well established. If excessive charges are used in blasting, a great deal of material is loosened up that fails to be removed. This neglect is extremely dangerous and leads to no end of disaster for a long time after traffic has begun. There is another cause of the falling of stones from gravelly and hard pan slopes against which I confess I know of no protection. Thus, a passenger train was descending the valley, and discovering a boulder on the track, blew the whistle for down brakes; instantly, a volley of small stones started from up the slope, and bounding toward the train, broke every window in a second-class nine-panel car, terrifying the passengers, who took refuge on the road-bed under the car. It was no uncommon occurrence for cobble stones, to break loose and roll down the slopes in response to the engine driver's whistle.

An accident occurred to the engineer's camp at Huaurachiri, quite distinct from all others, and, indeed, from any I have ever known. The camp was on a low pampa, the engineer's house being probably 200 feet

from the river-side; in the stream and along the bank were several boulders, ranging in size from 3 to 10 feet in diameter. On the bank and near these boulders were the servants' houses and the storing department. There could be no doubt that these boulders had rolled from the upper slopes of the cliffs on the opposite side of the river, and when they reached the vertical face had acquired such momentum as to be thrown clear across the stream. But one night a boulder 5 or 6 feet in diameter was precipitated from the lofty slope and thrown at such an angle upon the inside edge of a similar boulder lying in the river, that a ricochet took place; it leaped clear over the servants' camp, and plunged directly into the middle room of the engineer's house, carrying with it a part of the roof, the eaves and wall of the little structure.

These observations have taken up a good deal of time and space. I think it will be found, however, on careful analysis, that I have indulged in no relation that is not of practical value to engineers, contractors and all persons interested in the construction of cañon lines.

In conclusion I beg you to indulge me in telling the story of a remarkable rescue of a member of a party engaged in the preliminary surveys of the Chimbote Valley. One of the men, an American noted for his agility, had been sent down from a trail high up on the mountain slope, to learn if there were a point where with an instrument he could observe a certain peak already located in the surveys. It was necessary to descend a slope of say 45 degrees, on earth overlying the mountain rock. A little distance below was the edge of the precipice, a sheer height of 600 feet above the river. When the assistant had reached half way down between the trail and the cliff, the earth on which he walked began slowly to slide upon its smooth rocky bed, falling in a cascade over the bluff, and after its start moving with accelerated speed. There was no apparent escape for the unfortunate man; he threw himself prone upon the ground, and drawing his sheath knife, thrust it into the earth and shortly found a crevice in the rock by which to hold himself where he lay. Already a Cholo axeman had forced a crow-bar into the ground at the trail, and clutching it in both hands, had thrown himself, feet down, the slope. In an instant another descended by his side, and, holding by the ankles of the first, was followed by enough men of the party to make a living rope that reached their comrade in danger, who, by this support, completed the observation and ascended the slope to a place of safety, followed by the successive members of the line. After this a light rope became a constant part of the outfit of such parties.

O. F. Nichols, M. Am. Soc. C. E.—I have been much interested in Major Sears' account of his recent experiences in the valley of the Santa in Peru, and I am glad to hear again of the work with which I was, some years ago, intimately connected. I read Mr. Stanton's paper carefully, and found it exceedingly interesting. It seems to me that this

projected railway through the cañon of the Colorado would open up the great Southwest, of which we know so little, in a manner not otherwise practicable. The line would run diagonally Southwest from near Denver, and reaching a point near Yuma, and thence moving westerly, cross the mountains at a relatively low elevation, and reach the ocean near San Diego, California. The line of this route from the Northwest would be something more than five hundred miles shorter than any of the routes now in use. The river has a very gradual fall and the grades would be remarkably easy and much lower than those on any of the other transconti nental lines.

Mr. Stanton has necessarily introduced a great number of tunnels, so that a large portion of the line would be built in tunnel. Any criticisms I may make will be made, as they should be, in a very modest way by a person who has never been through the cañon. Mr. Stanton deserves great credit for the skill and persistency with which he overcame all obstacles and accomplished this very difficult survey, which bears the marks of energy and accuracy.

Much of the work, Mr. Stanton says, could be done with scraper, referring to those portions located on the flats or sand bars left by the river at the prominent bends. Major Sears has explained how similar work was subsequently cut out by the recent floods of the Santa, on the Chimbote line. On the Santa these flats, or pampas, are raised some 20 to 30 feet above the river, and are composed of gravel with about 10 per cent. of sand. This material had been compacted and consolidated under the water of the deep lakes of which they formed the beds. The rock dams forming the lakes were afterward cut out until the level of the River Santa was so lowered that it finally cut into the lake beds themselves, leaving this material standing high above the river, and here it had remained in a tropical climate which does not vary to exceed 15 to 20 degrees in the year. The top surface of the material became hardened and sun dried, so that picks and even blasting were required for its removal. In the middle Santa this material stands in retired cliffs, 300 to 500 feet high. I remember visiting Mr. Buck at his camp when he was erecting bridges 2 and 3 on the Chimbote line. He had located his house with flat roof of corrugated iron at the base of one of these cliffs. It was some feet from the cliff, and the face of the material was such that the gravel dropping out, under the action of the sun, would fall so as generally to clear his house. Occasionally it would fall short and strike the roof and sometimes penetrate. Fortunately for his friends as well as himself no fatality resulted, though there were narrow escapes.

These flats in the Colorado cannot be so hard and lasting as those in the Santa, and I should greatly prefer to avoid the use of them altogether, even at the expense of increasing the tunneling and rock work. On the Chimbote line the mistake was made in the lower por-

tions of the line of following around too near the edges of these flats in order to lighten the work, the result being to increase distance and curvature, and expose the work too greatly to the danger of subsequent floods, then not anticipated. In the work on the upper Chimbote we endeavored to keep back on these flats as near the rock as possible, for economy of line and greater permanency.

At some points Mr. Stanton has shown alternative lines, one coming out of tunnel onto these flats, the other keeping inside entirely in tunnel. I believe it will be found wisest to build the inside line, even at the expense of lengthening the tunneling. The distance and curvature, both essentials in a trunk line, will thereby be lessened. The photographs of the Colorado Cañon show clearly that much of the line can be built in rock cutting on the comparatively easy slopes, and the talus slopes can be utilized where they are composed at the base of heavy stones and are not exposed to running slides from above. These running slides were a prominent feature of the Upper Oroza line in Peru, and necessity compelled their use. Fortunately no fatal accidents have resulted, although a locomotive had a rock of about 1 000 pounds weight crush through it, wrecking the cab and starting lever without killing the engineer and fireman, who were men of nerve and agility.

In the narrow gorges of the Colorado, where the walls are practically vertical and immeasurable, tunneling or gallery work is imperative. Galleries are quite practicable in good solid rock. At the entrance of the Chimbote Cañon, of Huyna Taquilpan, just below Tunnel Number 1, a gallery was designed. The location on the vertical cliff at this point was made by arranging a system of ropes, the upper line fastened to bolts placed in the rock by hanging men over the cliff, the lower line about five feet below it suspended by ropes strung diagonally from the upper line. The men walked on the lower rope holding fast to the upper. The two cañons are quite similar in one respect. No man ever fell into the Santa and lived. It is a rushing, roaring mountain torrent, deep enough to drown and rocky enough to kill; often with a 12-mile current; its surface, always turbulent, in daylight a picture of demoniac waters, at night waking the stillness by grinding huge boulders together in its bed. The Colorado is of this character at the rapids, although there are many places, as Mr. Stanton states, where boats can be used with ease and safety.

Mr. Stanton shows how wide the Colorado Valley often becomes at the top, reaching 15 to 20 miles in places. This would mean comparatively easy slopes suitable for rough construction roads, and these points are often quite near stations on the existing railways. This would seem to obviate the necessity of constructing this long railway from the two ends, and indicate that it might well be prosecuted from many intermediate points, perhaps as many as thirty or forty, thus shortening the

time necessary for construction. All the most approved methods of modern rock construction would be utilized, and all the tunnels would be driven either with compressed air or electrical machinery. At best, an immense time would be required in construction.

The Government reports show that the vast basin of the Colorado contains much land which, when the district is ultimately irrigated, will be suitable for the habitation of an immense population to be engaged in the cultivation of agricultural products. No other avenue exists for the accomplishment of the settlement and utilization of these now barren wastes, than that now presented in the skillful work of Mr. Stanton. He and his associates deserve great credit for accomplishing so much in the wildest cañon of the globe; and I sincerely trust that the author of this interesting paper may live to complete this great work which he has so well inaugurated.

SAMUEL M. ROWE, M. Am. Soc. C. E.—This report from Mr. Stanton, treating as it does of a portion of our country little known, but of which I have gained some knowledge from several years of professional acquaintance, possesses more than usual interest. In the three points, low grades, favorable climatic conditions and the facilities for water supply—such favorable conditions not obtaining in the case of either of the existing overland routes—Mr. Stanton gives strong points that will go far to counterbalance the seemingly unusual cost of construction. There is much of scientific value in this report to be added to our too limited knowledge of the region in question. His statement that "the glacial period was not icy but rainy," corresponds with my observations, and accounts for peculiar features of that region otherwise hard to reconcile with glacial action. The appearance of the Stanton party at the Colorado Bridge possessed to me all the interest of victorious veterans returning from a well fought battle. They are entitled to a greater measure of credit than can be conceived by any but those acquainted with the region traversed.

JOHN E. EARLY, M. Am. Soc. C. E.—I have read Mr. Robert B. Stanton's paper with much interest. A low grade line to the Pacific Ocean would undoubtedly be of great benefit to the country at large, and Mr. Stanton seems to have found a line which will also be a paying investment of itself. There can be but little doubt but that if this line is so "financed" and built that its capital account will not represent more, or much more, than its actual cost, it will be a paying investment to its builders. But we all know how much "water" can get into the capital stock of a railway during its construction and how this water keeps the line down during the first years of its operation.

I can give Mr. Stanton another point for traffic for this line, viz., a coal traffic for Mexico. Mexico is a country where fuel is both scarce and dear. Its only productive coal fields are near the Rio Grande, on the Texas frontier, and from present appearances no other profitable fields

will ever be discovered. At some time there will be railway connections with the Pacific, and it is probable that Mr. Stanton's line would be able to deliver coal at Pacific ports at such a price that it would be consumed on the railways and at the towns and mines of the Pacific slope of Mexico, with a chance of its use in the interior. I write the above, knowing that it is claimed there is good coal in the State of Sonora. This coal, however, is so situated that it will not be available without a railway, and this railway would be so dependent on the coal for its traffic that it should be considered as part of the plant for working the mine; furthermore, its amount is, in the opinion of experts, not sufficient to guarantee such an investment for plant. Whenever this coal comes to market it will come by a north and south line through eastern Sonora, as part of such a line's business; but this will hardly be for many years, and probably not for a long time after some line has been built down to the coast from the interior.

There have been many concessions given for railways to the Pacific by the Mexican Government, and with subventions; but the subventions have been so small in comparison with the estimated cost of construction and the prospects for business, that no company has yet seen fit to construct its line. It would not, however, be surprising if before long this work is undertaken, as the present policy of the Government seems to be to refuse to extend concessions with subventions and to declare them forfeited when they lapse; this is leading both the railway companies and the capitalists to make the most of the concessions now in hand. This is, perhaps, wandering from the subject, but may be taken as additional information of interest regarding the prospects for business of Mr. Stanton's line.

Mr. Stanton's paper brings out strongly the availability of cañons in general for railway construction. I think they are usually found more available than they appear at first examination. A railway line is so small and narrow a thing as compared with a cañon—even a narrow one—that it can be laid on the beaches and shelves and hung on the slopes of the cañon, without disturbing the main features of the topography. Even in the closest cañons, it is usually found that the really difficult portions which first catch the eye and which remain longest in the recollection, comprise only a small proportion of the length. The cañons furnish the lines of low grade through the mountains, and in many cases the resistance to traffic is given by the resistance of the curve of minimum radius rather than by the fall, so that there is a maximum grade greater than the fall of the cañon, which can be used without detriment, which allows the position of the line to be varied on the sides of the cañon within moderate limits, in seeking for the best ground. Many such variations result in a cheapening of the line below the estimates from the reconnoissance.

I note the difficulties of the reconnoissance and the use of photog-

raphy. Engineers seem able to go, as a matter of business, wherever there is need for them. A friend used to say that the entrance to the interior of Africa would be found and no fuss made or books written about it, when some engineer started out to find a line for a railway into it. The use of a reconnoissance and report on a line of railway being to give the projectors and possible investors as clear an idea as possible of it, I consider the photographs obtained as of the greatest value.

I note that the work can be carried on from many points at once and this will be of great advantage. Without doubt other ways of entering the cañon will be found if they are required. Mule or jack trails are not hard to find, and the cost of transportation of tools and supplies for construction by them does not add much to the cost of a line. Probably advantage would be taken of times of high water to send supplies down the river by flat boats, as coal is now sent down the Cumberland River, the boats not returning but being sold for other purposes.

From Mr. Stanton's paper, it seems to me that the line should be built, that it will pay for building, and that Mr. Stanton, if he should build it, would probably find, when the accounts are all in, that he has not underestimated the difficulties and cost.

J. Francis Le Baron, M. Am. Soc. C. E.—After reading Mr. Stanton's very clearly written paper, it would almost appear as if these cañons of the Colorado were made expressly for the purpose of a railroad line, as if nature, in the fulfillment of her beneficent plan, had cut these tremendous gorges through the everlasting hills to afford an easy passage for the commerce of a great country; but it required a bold and fearless mind to first grasp the value and possibilities of such a route, which at first sight might appear as a visionary or foolhardy scheme. The more the subject is studied, however, the greater its advantages appear. There is nothing in these days that the American engineer or contractor will fear to attempt, when backed by sound science and capital. The use of river valleys and gorges is and has been universal for railroad locations, but this project is unique in its fearlessness, grandeur and extent.

The location, by the writer, of the Petersborough and Shirley Railroad, through the Unconunuc and Monodnoc Mountains of New Hampshire, while not comparable with the line under discussion, afforded some details of a similar nature where the transit-man had to be lowered down to his station by ropes and the instrument taken off of the tripod and set up on the bare rock. Such instances are by no means rare on railroad surveys, even in the eastern portion of the United States. Such locations are often found more formidable in the survey than the construction. General Fremont's explorations for a railroad route over the Rocky Mountains were fully as dangerous, and the building of a transcontinental railroad appeared, at that time, far more impracticable than this line does now.

The construction of a railroad on such a location as is proposed through the Colorado Cañon, is infinitely easier than the construction of such a line as the Nicaragua Ship Canal Railroad, for instance; the location of which was made under the writer's direction, in a country where the annual rainfall is 320 inches per year, and which was limited at every step by the line of the canal itself and its flooded basins and embankments, rendering it necessary to lay out the line, for the most part, transverse to the natural drainage lines of the country through the divides of the Cordilleras. This is the railroad which is required to aid in the construction of the ship canal.

The availability of the proposed Colorado line for a grand trunk route, seems to be clearly shown by Mr. Stanton's interesting and graphic description; but this availability must, of course, be governed by the character of that part of the line from the terminus of the survey, or at Yuma, across the Sierra Nevadas to the Pacific Coast at San Diego, and of this I have no information except in a general way. Many of the details of construction through these cañons will undoubtedly be rendered more feasible and less expensive if a careful location should be made. For instance, the long aggregate of river embankments, which I would consider highly dangerous and expensive in a river of this character, can perhaps be avoided by crossing the stream, or by raising the grade for some distance. The so-called half tunnels can probably be blasted out in great masses by drilling horizontally from platforms suspended by ropes in front of the scarp wall, and it may be that some of the timber and ties can be floated down the river to available points, reducing the cost of transportation.

The absence of snow in winter will largely reduce the cost of operation and maintenance of this line, which is a great point in its favor as compared with other lines; as is also the abundance of water for the engines, the freedom from caving or washing earth banks, and the great abundance of stone ballast.

It would seem that the local freight traffic of this road will be largely mineral, collected along the line, for distribution at the termini. The fact of its low level, making all its branches have a down grade to it, will be an advantage, and it seems certain that it never will be vexed with grade crossings and damages arising therefrom.

The question of "Will it pay?" may properly be included in a discussion of general availability, and the first thing that occurs to me is the unique fact that, from the necessity of its location, it cannot pass through any sites of future large cities, although it may possibly some day find itself near the suburbs of some metropolis yet to be built. This might be looked upon as an advantage in many ways rather than otherwise; for instance, by lessening the labors of the legal department in the matter of damages and claims for injuries to persons, teams and cattle on the track, the costs of fences and gates, and expenses for right of way and depot grounds.

The relative capacity and operating expenses of such a road, with no grades higher than one-half of 1 per cent., as compared with a high level road, with grades of 2 to 2½ per cent., is the most important point to be considered in the question, Will it pay? and would seem of itself to decide the question in the affirmative, especially as the curvature is probably no sharper than in many cases would be necessary on a high level road. According to Wellington's most excellent treatise on Railway Locations, the ratio of gross weight of train to tractive power required is, for a grade of one-half of 1 per cent., 111.11, but with a grade of 2½ per cent. only 34.48. The net load of train in tons that can be hauled up a one-half per cent. grade varies from 504 to 1 357 tons, according as a very light or very heavy engine is used, while on a 2½ per cent. grade only 120 to 361 tons can be hauled. This means that a larger number of trains must be used to transport a given amount of freight, and where one train will suffice on a level track, it will require 2.33 on a grade of one-half per cent. and 8.79 trains on a grade of 2½ per cent. The cost per year of 1 000 ton miles daily over a one-half per cent. grade is stated to be $18.75, while over a 2½ per cent. grade it will be $26.72.

J. Foster Crowell, M. Am. Soc. C. E.—For those of us who were present on the occasion which Mr. Stanton refers to, at Cresson, viewed his remarkable photographic ensemble of the cañon and listened with eager interest to his narration of the difficulties and perils of the survey through those stupendous gorges—this paper, giving its results, possesses an added interest. To those who were not so fortunate it may be mentioned, that Mr. Stanton's reference to the photographic features fails to give an adequate idea of the very comprehensive and satisfactory showing that these photographs make of the characteristics of the various cañons, of their formation and of the topographical details of the cañon walls, throughout the many miles which the series embraced, as Mr. Stanton says, almost continuously. The lantern exhibition of these views was not only demonstrative as to the object, but also of the great value of the camera as a surveying instrument. To it is largely due the fact that this examination, which otherwise would have been but a reconnoissance, possesses the value of a careful preliminary survey.

The character of the paper is such that intelligent discussion in detail is not within the resources of those who are not fully acquainted with the region of the cañons; as I am of that number, I shall confine my brief comment to a word upon the considerations which to me seem to recommend Stanton's route, assuming its entire availability to be demonstrated. First of all and more than all, is its low grade feature. Railroad projectors have become so inured to high gradients that 4, 5 and even 6 per cent. are not deemed obstacles to a location. The projectors ascertain the latest performance of locomotives as grade climbers and govern themselves accordingly. Afterward, when the roads

are completed and the operating officers begin their never-ending and ruinous struggle against the laws of gravity, it is generally too late to correct the evil and the road is handicapped for all time. The enormous advantage of a line with a maximum grade in either direction of not more than one-half of 1 per cent. as against the present high grade lines southwest of Denver, is too apparent to be dwelt upon. Mr. Stanton states that even a lighter ruling is practicable. But, of course, the ultimate success of a railroad depends upon the amount of traffic, and it is probably true that in this year the traffic in suitable volume to predicate the commercial success of this proposed road is not within sight. It by no means follows that it will not appear speedily. We in the East are apt to regard all such projects from the transcontinental point of view; the applicability of a railroad through the Colorado cañons has this point of view, but only in a minor sense; its true function would be to aid in developing the Southern Pacific coast. What that development will call for upon the completion of the Nicaragua Canal, or even without it, can only be conjectured, but we may safely presume that the requirements will be vast. A second important recommendation of the cañon route is its comparative freedom from snow; a very valuable feature from the standpoint of both the operating and traffic departments, besides saving the enormous outlay in first cost and maintenance of snow sheds and chutes, where necessary on the mountain lines.

Mr. Stanton has put in evidence the indications which refer to the possibility of local development, which would seem to confirm the future success of the proposed line as far west as Yuma, independently of the commerce to be reached hereafter at the port of San Diego. Whatever may be the outcome, we as engineers should congratulate our fellow-member and his associates upon the thorough and admirable manner in which this exploration and survey have been carried out in the face of almost insuperable difficulties and amid disaster and death; that is an achievement in itself of which they may well be proud.

As a voyager of some little experience in exploring and navigating rivers beset with rapids, I would add a word as to the best form of boats to be used; this at first sight appears to be an unimportant detail, but as the sad sequel proved, in this expedition it was the most important. Mr. Stanton describes the improved cedar boats built for the second attempt in the light of the first disastrous experience and they appear to have rendered good service. But a canoe-shaped boat built of steel, on whaleboat lines, with air compartments fore and aft and propelled with paddles instead of oars, can be made much lighter, is non-sinkable, and will stand the roughest usage and most violent concussions without detriment. Such boats are used by the Nicaragua Canal people and were the outcome of many years of experience with wooden ship's boats and native canoes. Their cost is not great; they can be transported any-

where without injury, have no seams to open, and can be quickly repaired. As an auxiliary transport for provisions, records, ammunition and other perishable articles, I would recommend air-tight metallic balsas, in pairs, fitted either for being paddled or lowered, or dragged up through rapids in cases where open boats could not be kept dry. As speed is no object in the balsas, they can be made very roomy and strong at both ends; and they should be provided with two or more packing holes, secured with air-tight covers for getting at the cargo.

Mr. Stanton has referred to the possibility of making use of the water power in the cañons for generating electricity to be applied to rock drilling. This seems entirely feasible and the power would appear to be inexhaustible, so that not rock drills alone, but devices for removing débris, laying up rock slopes and setting masonry, and contractor's locomotives, could also be operated. Indeed it is not altogether visionary to point out that by the time this railroad shall be constructed, it may become mechanically and commercially practicable to operate the entire railroad from end to end with the power of the cañon in electrical application.

Mr. Stanton shows a commendable conservatism in locating his line generally well back from the river in exposed localities. I think he will be entirely justified in adopting the alternative lines he has indicated and even in pursuing this policy to a still greater extent; thus, while requiring greater length of tunnel and increasing the first cost, he may avoid dependence on the talus where any doubt exists as to its permanent stability. It is quite true that important lines and structures are not infrequently founded on talus, but it is wiser not to allow it to constitute a sole dependence where other and safer possibilities exist. This remark applies with still greater force to the flats, whose permanence must always be problematical. This is not offered as adverse criticism, but only by way of emphasizing a consideration which has already been placed before us in the paper. The safer line is, in the case of the more difficult portions, the shorter, and the condensed classification of the Glen Cañon Division shows that in the alternative location "B," there is a saving of 18½ miles of line gained at the expense of 6¾ miles of rock tunnel. Figures of cost are not given, but if we assume average prices and capitalize at 5 per cent. annually the cost of maintenance, renewals and operating the 18½ miles of distance saved, computed on a basis of moderate traffic,—we will find that the excess in first cost will be very nearly balanced, not taking into account the value of insurance against risk and the saving in time to passengers, both tending to augment travel.

But even in cases where the financial showing would not be so favorable, I believe this course should be followed irrespective of first cost, and the line located, as the author of the paper has well stated elsewhere, "on as permanent and safe ground as the nature of the cañon walls will

permit, believing as I do that this 'railroad of the future' should be built for ultimate value and profit even at a much greater cost."

LATHAM ANDERSON, M. Am. Soc. C. E.—Mr. Stanton's paper is a valuable contribution to our knowledge of the geography of this continent, and also to his daring enterprise in prosecuting the survey. It is interesting to know that a railroad can be constructed through this mighty chasm. It is always pleasing, especially to members of our profession, to see any new instance of the subjugation of matter to mind in overcoming apparently insurmountable obstacles. Apart from these considerations, the benefit of this survey is not apparent. In the opinion of the writer there is no equal area of the earth's surface in any civilized country in which a railroad would be of so little practicable benefit. If the sole object be to transport the coal of Utah to the Pacific Coast, a much shorter and better line could certainly be found; *e. g.*, beginning, say, at Frisco (the present terminus of a line of railroad), running thence southwestwardly in the vicinity of Pioche, through Vegas Valley, and south of the Amargosa Desert, up the Valley of the Mojave to Barstow, on the Atlantic and Pacific Railroad. Most of the country traversed by the line just described is about as inhospitable a desert as can be found on the face of the earth. But it has one crowning advantage over the line in the chasm; that is, the people living on either side of the road could get to the cars. The desert just described is bad enough, but it has some oases scattered through it. There are rich mining districts of the precious metals, and there is so much open country to traverse, that there is every reason to presume the line would be less costly than the line in the Cañon. As you approach this abyss, the plains on either side are rent by chasms similar in character to the Grand Cañon itself, and these have side cañons equally precipitous. This great table land, interspersed with mountain summits, becomes more and more sterile and unproductive as you approach the main river. Water is at least as scarce here as on any part of the desert. Even where gold or silver mines exist, fuel and water are so scarce and access to the country so difficult, that the mining of even the highest grade of ores must prove unremunerative. Imagine a man working a mine near the brink of such a precipice. He may be within sight or even within hearing of the cars a mile below him, but it would require a half day's journey down precipitous roads to get to the nearest station, and, of course, still more of an undertaking to climb back again.

The fact that the expedition found some evidence of gold in the river or mesa gravel at several points on the route, cuts no figure at all in overcoming such insuperable obstacles to the profitable operation of a railroad in the bottom of such an inaccessible hole as this.

J. L. BARLOW, M. Am. Soc. C. E.—Mr. Stanton divides his paper into two questions, first as to the feasibility of the Colorado for a railway line, and second as to its advisability. The feasibility of the

Colorado for railroad purposes becomes a matter of little interest, unless its construction can be shown to be a business proposition and one which gives promise of answering the question of its advisability in the affirmative.

Mr. Stanton's tables of classification show a very heavy line; to construct probably $40 000 per mile for its entire distance would be a moderate estimate, or perhaps $40 000 000 or $50 000 000 to build from Grand Junction to San Diego, its one advantage being that it is a very low grade line for the greater portion of its distance.

The Union Pacific now has its grade completed to a point 30 miles south of Pioche, Nevada, to tap the mines in that district, and complete surveys southwest into California (the ruling maximum grade being 1 per cent.) show, that at such time as it may be deemed advisable, the connecting link can be built at from 10 to 12 per cent. of the cost of the Colorado Cañon route, thus completing a substantially parallel line to the Colorado River, answering all the commercial purposes of the latter, and a shorter through line to the East, going via Salt Lake and Ogden instead of via Denver. The same comparative portions of each route, taken by adding the construction cost and capitalized value of operating any probable amount of traffic they may have, will show unfavorably to the Colorado Cañon route.

The writer is also familiar with a considerable portion of the route surveyed by a new company about two years ago, from the vicinity of Grand Junction to Southern California, averaging to run parallel to the Colorado River on the north and west side, at a distance varying from 25 to 150 miles, which, when compared to the Colorado Cañon route, will also show the same result as above, though perhaps in a lesser degree.

The winter of 1889-90, in regard to snowfall and railway blockades, was the most serious in many years in the western portion of the United States; yet the snow was never deep enough in southern Utah to seriously impede the writer's progress, and he traveled many hundred miles by buckboard along the routes of survey in making the reconnoissance, and often on no wagon roads.

The question of any given route's feasibility is very largely of a comparative nature, and while the writer has no personal knowledge of the Colorado River and its cañons, except below the mouth of the Rio Virgin, yet from Mr. Stanton's description of the route above that point and his own observation below, as compared with the completion of another route already partly built, or the construction of a new and totally different one as indicated above,—he is inclined from such a standpoint to doubt the feasibility of the cañon route.

As regards its advisability or the question of "Will it pay?" Mr. Stanton indicates its three main sources of revenue, viz.: 1. Its share in the transcontinental business. 2. Colorado and Utah coal traffic to

South California. 3. Local business. In regard to the first, there are already two transcontinental roads competing for Southern California business direct, while a third (the Union Pacific) indirectly forms an active competitor via the Central Pacific and San Francisco—all three roads maintaining traffic agencies in Southern California, with through freight lines and passenger coaches. With three competing rail lines and the probability of another formidable competitor in the Nicaragua Canal, it will be seen that the Colorado Cañon route can command but a small proportion of the transcontinental business, and that, in turn, practically confined to the district of Southern California.

Concerning the second, or coal traffic, the British Columbia and Puget Sound coal, mined at or near tide water, is carried by steam colliers to San Francisco for $2 per ton, and Southern California for $3 per ton. Mr. Stanton cites even San Francisco as within the scope of the coal business of the new road. In order to successfuly compete can this proposed route carry Colorado coal to Southern California for one-quarter of a cent per ton mile? Or from Utah at one-third of a cent per ton mile? And to compete in San Francisco the rate would have to be about one-eighth and one-sixth cents per ton mile respectively.

In regard to the third source of revenue—the local business—it can only be a matter of conjecture, but the writer believes that, taken as a whole, there is no other stretch of a thousand miles of country in America which is more barren or gives less prospect of developing local business for a railroad than does this. And the advantage claimed with regard to local business by reason of being in the bottom of these comparatively narrow valleys and cañons, can, with equal force, be urged against it, by reason of inaccessibility from a comparatively wide belt of tributary country. Aside from these questions, the boldness and nerve required to successfully carry out such a hazardous expedition, and the value of this research as an exploration and engineering reconnoissance, will be appreciated by every engineer who reads Mr. Stanton's paper.

Lewis Kingman, M. Am. Soc. C. E.—I have read with much pleasure and interest Mr. Stanton's paper on his Colorado Cañon survey. The difficulties and dangers overcome have been great; the results are valuable and highly commendable; it has been demonstrated that a railway can be constructed through the Grand Cañon and that it can be done within reasonable limits of cost for cañon work. I have spent two decades on railway location and construction in the Southwest, and two years in charge of the location of the Atlantic and Pacific Railroad, through northern Arizona, from the Little Colorado to the Needles on the Colorado River; a distance of nearly 300 miles in the country south of the Grand Cañon.

I would congratulate Mr. Stanton on being alive and well. It is not often that an engineer is accompanied on an exploring expedition by the President of the company, he is usually sent with the best wishes of the

higher officials. We have heard of proposed laws requiring the President to ride on the cow-catcher to insure the safety of his trains; but in this instance a railroad president volunteers to go to the front on a most hazardous expedition and loses his life. I think President Brown should have a monument as high as the walls of the Grand Cañon to commemorate, among men, an act so rare.

I do not question the practicability of building a road through the cañon; engineers can do almost anything if there is really an inducement for capital to support them, and a reasonable assurance that it will pay. A line from Colorado to the Pacific passes over a country of magnificent distances. From Grand River to the Rio Virgin it is 668 miles; the line for the greater part of the distance is inaccessible, and there is but little inducement to build branch lines. The distance from Grand Junction to the Needles is 793 miles; the distance from the Needles via the Atlantic and Pacific Railroad to San Diego is 374 miles, an air line between the two points being about 215 miles. It is possible a line might be located saving 100 miles of the Atlantic and Pacific distance; we would then have 1 067 miles from Grand Junction to tide water at San Diego. The coal traffic would be one of the principal items of business for the new line through the cañon. Taking the cost of coal F. O. B. at Grand Junction to be $1 per ton and freight charges at three-fourths of a cent per ton-mile, it would cost delivered at San Diego $9 per ton. A railroad might be located from the southwest Utah coal fields via Rio Virgin and the Colorado River, and shorten the distance from the coal fields to San Diego to about 600 miles; then with coal costing $1 and freight three-fourths of a cent per ton-mile, coal would cost $5.50 per ton at San Diego, and if the quality was first-class they might control the market. On January 4th, 1892, Wellington, Scotch, English and Santa Fé coal was quoted worth from $8.25 to $8.75 F. O. B. at the wharf at San Diego. At Los Angeles, on the same date, Gallup, New Mexico, coal was selling for $8.50, and Wellington coal for $10 per ton. At San Francisco, on the 2d of January, 1892, the prices were as follows on 2 240 pounds to the ton, F. O. B. at the wharf:

Wellington	$7 25	Australian	$7 00
New Wellington	8 00	Pennsylvania anthracite	10 50
Naniamo	6 75	English coke	8 00
Seattle	5 00	Colorado anthracite, 2 000 pounds to the ton	12 50
Coos Bay	5 00		
English	7 00		

From Mr. Stanton's tables showing the amount of coal used at San Diego in the first six months of 1890, only 19 309 tons were received; this would be 38 618 tons a year, or 2 575 carloads; about 8 carloads a day; the whole would not make a very large item for any one railroad. One reason for the great difference in the prices of coal at San Diego

and San Francisco is the amount handled, another reason is that ships coming to San Diego cannot get any return cargoes. Mr. Stanton's tables indicate that there is about twenty-eight times the amount of coal received at San Francisco that there is at San Diego.

The distance from Gallup on the Atlantic and Pacific Railroad to San Diego is 791 miles. This is 276 miles nearer to San Diego than Grand Junction would be; yet the distance and cost of Gallup coal explains why only 2 000 tons of this coal were sent to San Diego in the years mentioned. At Los Angeles, where other coal has to be reloaded and shipped by rail, Gallup coal is sold for $8 50, a price which allows it to be used in competition with other coal. Colorado anthracite is sold now for $3 per ton of 2 000 pounds F. O. B. at Crested Butte. The distance to San Francisco is 1 394 miles, the freight to San Francisco is $9 50, which makes this coal cost $12 50 per ton of 2 000 pounds; while a ton of 2 240 pounds of Pennsylvania anthracite is sold F. O. B. at the wharf at San Francisco for $10 50. By the cañon line it would be 1 220 miles from Crested Butte to San Diego; then reckoning as before freight at three-quarters cent per ton, we would have the first cost of anthracite coal $3, freight $9 76, cost at San Diego $12 76, which would not allow it to compete with Pennsylvania anthracite. That coal and coke could be delivered and sold at San Diego from any place on the D. C. C. and Pacific Railroad, or its proposed branches, for from one-half to one-third the present market prices, does not seem apparent; they could not deliver coal at San Diego as cheap as the Puget Sound or Oregon coal is delivered at San Francisco; for that reason they could not expect to ship any from there along the coast, and, if not, they would have to rely upon the San Diego consumption, which is very small.

As to the passenger business, distance is always an important factor. Then again, the movement of passengers is somewhat in proportion to the population and the business. San Diego has a population of 16 153, Los Angeles 50 304, and San Francisco 298 000. We should expect three passengers to go to Los Angelos to one to San Diego; and nineteen to go to San Francisco to one to San Diego.

Comparing the coal business of the two places, we should expect twenty-eight passengers to go to San Francisco to one to San Diego. The distance from Denver to the Needles via Grand Junction and the cañon would be 1 218 miles. The distance from Denver to the Needles via the Santa Fé, La Junta and Albuquerque is only 1 102 miles. The distance from Denver to San Diego via Grand Junction and the cañon, with a new line from the Needles to San Diego, 100 miles shorter than the Atlantic and Pacific, would be 1 492 miles. The distance from Denver via the Santa Fé, La Junta and Albuquerque to San Diego is only 1 476 miles, and passengers going to or from points east of Denver would find the distance much more in favor of the Santa Fé. There would be some passengers who would go to see the cañon, but 700 miles of cañon would become rather tedious and monotonous.

At the time the Atlantic and Pacific Railroad was built there were parties who talked of building a hotel at or near the mouth of Diamond Creek, 25 miles north of Peach Spring, constructing several steamboats and improving several riffles in the cañon, so as to take passengers far enough up to get a good view; but the project was never carried out, as no one was ever convinced that it would pay. I visited the salt cliffs along the Rio Virgin. It is a wonderful sight, cliffs and hills of salt standing high above the valley, usually capped with a few feet of mud rock; the salt had been mined and used by smelting works, but distance and bad roads were too much to contend against. Occasionally some of the salt is clear and transparent, but the most of it would have to be refined for domestic uses.

The agricultural resources of the country adjacent to the cañon are overestimated by most every one, I think. Its value for grazing purposes is limited by the absence of water. The valley of the Colorado from the Rio Virgin down is greatly damaged by salt. There is no good grass growing from the Rio Virgin down. The earlier engineering expeditions often had to subsist their mules on mesquite beans gathered by the Indians. Wheat does fairly well on selected soil; but cottonwood trees usually grow to be from 4 to 6 inches in diameter and then die as soon as their roots reach the salty subsoil. One great trouble with the whole country is that it is too well drained. Water is not often found and when found it is in small quantities. On the Atlantic and Pacific Railroad at Winslow, while I was in charge, we sank a well 1 800 feet deep. The surface water was cased off, and when the well was tested there were but six barrels of salt, bitter water pumped every twenty-four hours.

At Ash Fork a well was sunk 900 feet deep, water was hauled from Hardy, 126 miles, to drill with, and often drilling was performed with difficulty, as the water ran out through crevices and left the tools almost dry. Finally the tools became fast in a fissure and work was abandoned.

The mining interests in the country are considerable, but many mining companies have failed on account of the cost of fuel and supplies. They do not realize that distance regulates cost even on railroads, and many of the mines are away from railroads, where the wagon freight over sandy roads is greater than the cost of the long haul on the railroads. The mines in northern Arizona were expected to develop when the Atlantic and Pacific Railroad was completed, but the results are not flattering. In conclusion, it seems to me that the Colorado Cañon line, with its terminus at San Diego, is not in the direction of travel or traffic. Passengers would desert the line at the first opportunity to go to San Francisco, San Bernardino or Los Angeles. A short line from the Needles to San Diego would not reach the productive part of Southern California. The tendency would be for freight to follow passengers,

but distance would operate against this and the line would be practically shut off from the California business.

ROBERT B. STANTON, M. Am. Soc. C. E.—It is gratifying that the interest manifested in my paper has brought out so extended a discussion. Some points seem to call for explanation, though I shall endeavor not to extend my remarks to any great length.

I am fully aware of the value of "skilled labor" in any undertaking, under ordinary circumstances. Yet in selecting my men for the second expedition, although strongly advised to secure the lumbermen Mr. Sears refers to, I rejected all such labor with but one exception, an experienced boatman in such waters, and he deserted the expedition in the Grand Cañon when we most needed him. It has been my experience many times during the past twenty years that for such work, whether on land or water, where prolonged hardships and privations, and especially scanty food, and perhaps starvation, are to be faced day after day, the man who has an object to gain, with of course the qualities of body and mind to quickly acquire "experience," is far more efficient, and the better man to tie to in a wilderness, than the laborer, however skilled he may be, who is simply hired for so much a day.

No one could have rendered more faithful service or have more skillfully saved our lives by his quick-witted work just in the nick of time, than my First Assistant, Mr. John Hislop, C. E., and while all the men who made the entire trip with me did their whole duty, yet the one who in less than a week developed the most perfect skill in navigating that rushing torrent with a heavy boat, was Mr. Reginald Travers, whose only preparation for such work, from the time he was seventeen till he was twenty-eight, when he joined the expedition, was that of a stock broker on one of the New York exchanges, and an amateur oarsman on Flushing Bay.

Mr. Sears and Mr. Nichols are each led into one error when they quote me as saying the road could only be built from the two ends. This is fully set out on pages 318 and 319, where I say that "work in the Cañon Division could be carried on simultaneously at at least forty different places," by existing roads and trails into the cañons on both sides of the river.

I certainly appreciate what these same gentlemen, and others, say in regard to the effects of great storms on work built on earth and gravel flats in cañons, having had some experience with such destructive forces in Clear Creek Cañon while engaged on the Union Pacific Railway. If called upon to build this line, I would use as my principle of location the quotation made by Mr. Crowell from one of my letters, that of placing the road-bed "on as permanent and safe ground as the nature of the cañon walls will permit, believing as I do that this 'railway of the future' should be built for ultimate value and profit even at a much greater cost."

As to the flats, which I suggested in my paper as available for use, and which would constitute plow and scraper work in the Cañon Division, the much larger number are in Glen Cañon, where for 150 miles the river has an average fall of 2.17 feet per mile, and where the flats exist, of about five-tenths of a foot per mile, and is from 1 000 to 1 800 feet in width. With these features, and the heavy rock work necessary in almost every instance at the upper approach to the earthwork, it is believed that these portions of the line can be made perfectly secure, except from a cloud burst directly over the roadway, which contingency cannot be provided for even on the dry plains of Nebraska. Of the remaining flats in the steeper portions of the cañons, and the 51 miles of "hillside slopes" in the Grand Cañon, almost every mile is situated on top of the first rock bench, with a vertical or sloping wall of from 10 to 80 feet of solid rock next to the water, protecting the earthwork from being undermined by the river.

These features are clearly shown at every point by the series of photographs, and also the necessity, and it is believed the perfect security, of the short stretches of "embankment in the river" in Glen Cañon, to which these gentlemen and Mr. Le Baron call attention. These embankments would be but newly formed talus slopes built entirely of solid rock, which Mr. Nichols says "can be utilized where they are composed at the base of heavy stones, and are not exposed to running slides from above," conditions which would exist in every instance. The experience of these gentlemen in Peru is most valuable, and I only hope that I shall have the opportunity of profiting by it in the cañons of the Colorado.

No one engaged in the investigation of a subject like that under consideration, can more highly appreciate adverse criticism than I, when it throws any light upon one's errors of judgment, want of experience, or facts. Mr. Latham Anderson does me the honor to say that my paper "is a valuable contribution to our knowledge of the geography of this continent." It is to be regretted that Mr. Anderson did not take advantage of the geographical information and other facts therein contained, when he wrote his part of the discussion. Nowhere have I stated that the "sole object" of this proposed railway is to transport the coal of Utah to the Pacific Coast. But assuming this to be the case, Mr. Anderson proceeds to point out a line from Frisco to Barstow, and says, "it has one crowning advantage over the line in the chasm." This is simply begging the question. A slight use of the valuable geographical information will show that no earthly comparison can possibly exist between his suggested line and my line "in the chasm," for the portion of my line from the Utah coal fields has not one foot of its length "in the chasm," or "in the cañon." Where it is, and what it is, certainly is clearly set out on pages 315, 329, 330 and 331.

I accept, without a question, Mr. Anderson's description of the

country through which his proposed line would run. Nor do I doubt for one moment that there exist along it "rich mining districts of the precious metals." Yet Mr. Anderson wipes out with one stroke of his pen all the evidence in existence of the mineral deposits of Lost and Gold Basins, Mineral Park and Eldorado Cañon, and the whole country tributary to the Colorado, from the Virgin to San Diego. The evidence is given in brief on page 330. A little use of the geological as well as other facts given in the paper, would have saved Mr. Anderson the trouble of perching his imaginary mining man a mile high on the brink of the precipice, and his sympathy for the tired legs of his friend, even though he were in the position assumed, would all vanish if Mr. Anderson would make a visit to Ouray, Colorado, and examine the toll road built from the town to the mines above, around a precipice as formidable for wagon road purposes as any in the Grand Cañon, and witness the ore wagons, each loaded with three tons of ore, rolling down that smooth and narrow way. Transfer that picture to the great ore bodies in the Grand and Side Cañons from "100 to 1 000 feet above the river, and from 4 000 to 5 000 feet below the plateau country" (page 329), and I think my case is made.

Every one is entitled to his own opinion; but before one accepts the sweeping assertions of Mr. Anderson and Mr. Barlow in the face of actual facts given, it might be well for one to consider some of the "inhospitable and barren" regions of the State of Colorado, and note their past and present local railroad business, and carefully read a folder issued by the Northern Pacific Railroad containing the famous speech of the Hon. Proctor Knott, of Kentucky, on the City of Duluth, delivered in 1871.

Mr. Barlow falls into the same unpardonable error with Mr. Anderson, when he compares the cost of the "entire distance" of the Cañon route with the cost of the Union Pacific line from Milford west. The only possible just comparison must be made, as Mr. Barlow suggests (but does not follow), of the "same portions of each route." Within the last year I have made some quite extensive examinations of various crossings of the Sierra Nevadas from Tuolumne County, California, south to the Mexican line, and I confess myself considerably surprised to learn, as Mr. Barlow states, that a railroad "can be built" across these mountains at a cost of from $4 000 to $4 800 per mile. The comparisons that Mr. Barlow assumes, but does not make, say from San Diego east to even points Cheyenne and Denver, would make a most interesting paper from him, and I shall be glad to furnish him with all information in regard to the Cañon route. Will he kindly accept the offer? It was distinctly stated that the question in its full bearing, "Will it pay?" was "outside the scope of this paper." However, the remarks of Mr. Barlow and Mr. Kingman are pertinent.

Mr. Barlow's answers to the three sources of revenue are somewhat

surprising. *First.*—His statements clearly imply that no one road can ever have any advantage over others in through traffic except in the ability of its traffic agencies to secure the business. I need only suggest a reading of the clear statements of Mr. Rowe and Mr. Crowell on this point. He also assumes that all transcontinental business for this line must be "confined to the district of Southern California," an assumption completely answered by himself when he says that the Union and Central (and I may add the Northern and Canadian) Pacific roads compete for this California business.

Second.—His estimates of cost of transportation are based on two errors, the selling price of coal at San Diego and San Francisco, and the contemplated methods of final distribution. I need not occupy the space to correct these. Mr. Kingman brings them out much more clearly.

Third.—Mr. Barlow's answer to the question of local business, is simply an opinion of an extensive mineral country—of gold, silver, lead, copper, iron and coal, of which he says he has no personal knowledge.

Mr. Kingman, it seems to me, occupies two or three very untenable positions. His figures and facts are interesting, but not complete. Analyzing his statements, the first position taken is that no road can have any advantage over another in the transportation of coal (and I suppose other freight) except in the matter of distance. If this were the case we should give up all attempts to better the grades, etc , of existing roads and stop building new ones except in absolutely straight lines.

I claim for the proposed road the advantages so well put by Mr. Rowe and others, over existing railways through the same section of country, not only for coal, but for all through and local business of whatever kind. If the cost of coal freight over the Atlantic and Pacific Railroad is, as Mr. Kingman states, three-quarters of a cent per ton-mile, I claim for the cañon route one-half of a cent per ton-mile. See profiles and statements of grades, etc., etc.

There are some slight discrepancies in the various distances given by us over the Santa Fé system. Mine were taken from their folder and may be wrong. The distance from Gallup to Needles is given as 420 miles. Using Mr. Kingman's figures, this Gallup coal costs at Needles $4 15 per ton. From the Utah coal fields to Needles by the Virgin and Colorado River lines (taking Mr. Kingman's distance to San Diego—600 miles) is 236 miles. Coal as before at $1, and freight at one-half cent per ton-mile, would cost $2 18 at the Needles. Which would allow it to go nearly 150 miles east over the Atlantic and Pacific till it met the Gallup coal in price, and would forever drive Gallup coal out of any California market, even over their own road. Of course I only take into account Mr. Kingman's position of cost and carriage and make no note of unbalanced grades or freights East and West. If quality be considered, even Colorado coal at one-half cent per ton-mile could be delivered at Needles

and supply the Atlantic and Pacific with all they use at that point and in California as against Gallup coal. To a much greater extent would these results obtain at Yuma with the Southern Pacific road. It is not necessary to give the figures.

The prices of foreign coal at San Francisco, Los Angeles and San Diego given by Mr. Kingman are of course correct. But coal of a quality equal to the Wellington by the Colorado River line at one-half cent per ton-mile, would cost at San Diego $4 per ton of 2 000 pounds, and by water to San Francisco per ton of 2 240 pounds only $5 43, as against $8 25 to $8 75 in San Diego, and $7 to $8 (of like quality) in San Francisco. The same coal could be carried by the Atlantic and Pacific road from Needles to Los Angeles and on the same basis sold for $5 05, and even from San Diego by rail for $5 55 (allowing three-quarter cent freight from Needles to San Diego), as against $8 50 and $10 for Gallup and Wellington; again using Mr. Kingman's figures, and the long ton. Hence, I fail to see why the market for the Colorado River road's coal should be confined exclusively to the present demand of San Diego. My statement that coal could be sold for one-half to one-third the present market price, was intended to be confined to the port of San Diego and the coal and coke of Utah.

The last position taken by Mr. Kingman strikes me as the most remarkable of all, that were this line built, its passenger and freight business would be, and forever remain, as compared with lines terminating at other points in California, in the exact proportion with the present coal trade and the present population of the cities of San Diego, Los Angeles and San Francisco.

With good coal at San Diego at $4 per ton (and this could be done F. O. B. of vessel, per ton of 2 240 pounds), the whole situation would be changed. There would then not only be 38 000 tons to be delivered at San Diego, but the whole supply for the two railroads at Needles and Yuma, and the mining, milling and smelting industries of the whole lower Colorado valley, the whole supply of San Diego, Los Angeles, and all Southern and Lower California, and a portion at least of the consumption of San Francisco. To these would be added the whole south coast coal trade, Central and part of South America, and Mr. Earley's suggested market in Mexico, and, as I am informed by the largest coal dealers on the coast, many of the coaling stations on the Pacific.

There would then not be, as Mr. Kingman says, only eight cars per day of coal business for the new road, but nearer one hundred and fifty to two hundred cars per day within a short time after completion.

With such conditions and prices, San Diego, becoming an exporting instead of an importing coal station, the whole traffic of the South Pacific would be adjusted on new lines. An ocean traffic would be attracted to this port much larger than at first sight could seem possible,

but all depending upon an unlimited supply of cheap fuel. It is not impossible that many of the now existing manufactories on the coast would move south to cheaper fuel and iron. Witness the departure of so many such industries from around Pittsburg to Alabama, Illinois and Indiana.

I do not for one moment recall anything said as to the extensive local interests of the upper cañons, or the great advantages of this line as a transcontinental route, but shall leave those to the simple statements of the paper itself, and add one point as to the prospective development of the far Southwest.

Mr. Kingman admits that "the mining interests of the country are considerable," and also shows just why the business is at a standstill, and then draws a dismal picture of the country through which the Atlantic and Pacific Railroad runs, and its failure to develop the mines of Northern Arizona. Ample reason for this is given in my paper. Allow me a moment to suppose a case. Consider the cañon road completed, with its many short and some long branches; at or near the mouth of the Virgin establish on the bank of the river, say, perhaps, at Old Callville, a milling and smelting plant for the reduction of gold, silver, lead, copper and iron ores. Into its mills and furnaces would pour, as into a funnel, by down hill railroads, from every point of the compass save one, the various ores from Southern Nevada, the precious metals, the iron and coal and coke from Southwestern Utah; and from Northwestern Arizona the ores and fluxes for hundreds of miles up the great cañons. Cheaply constructed branch lines would bring also the ores from those sections lying south and east of the river, and on account of the low grades, from far down the lower river valley. Does such a business as would certainly thus be developed, not only handling these raw materials, but the commercial necessities of so large a population as would thus be gathered together, depend in the least upon the depth of a dry well at Winslow or Ash Fork? The facts to show that this supposition is not beyond strict business principles can easily be had. Is there another point on any other present or prospective railroad in the section we are considering where such conditions can be brought together?

What, then, may yet be the local and through business of such a road in this far Southwest? Mr. Kingman is mistaken when he says no good grass grows in the lower Colorado Valley. I have walked through miles of it, and slept on acres of it, and have seen grapes, peaches, plums, pears, figs, pomegranates, nectarines, almonds, limes, oranges and lemons grow upon the banks of the Colorado and its tributaries at different points from the Virgin to the mouth of the river, and more are being planted every year. San Diego County, California, which is larger than the States of Massachusetts, Connecticut and Rhode Island combined, has, west of the Colorado basin, in its Spanish grants and

mountain ranches, over 1 000 000 acres of good fruit and grain land. Within the last two years new irrigation districts have been organized under the State law, covering over 250 000 acres, while there are completed or under construction private irrigation plants capable of watering 180 000 acres. In the year 1891 there were set out in this county 600 000 new fruit trees. What freight will this give a railroad? In 1890 from less than 3 500 acres—about 200 000 trees, besides smaller plants—the single station of Riverside shipped 1 800 car loads of fruit to the Eastern market. While one ranch near San Diego has the capacity, the climate, the soil and the water to produce more than ten times this amount of oranges, lemons and raisins.

Some one will say the Santa Fé already reaches this section with a short line to Chicago. Yes, and I have seen its trains standing in the yards at National City unable to depart for want of a tender of coal at any price.

But I must desist. Until it is better known the far Southwest will of course be misjudged. In conclusion, with a road such as I have suggested, with a long division possibly operated by electricity generated by the same power that cut those mighty cañons, and transcontinental transportation readjusted by the necessity of quicker time, cheaper freights, and the completion of the great canal, this line, with its low grades, favorable climatic conditions, its perfect water supply, its rapidly developed local business, and the attractions of its wonderful scenery, would in my humble opinion be able to earn dividends on a very high cost of construction—if that were necessary—while the upper transmountain lines could not carry on their business at the same prices and meet its competition.

PLATE XXVI.
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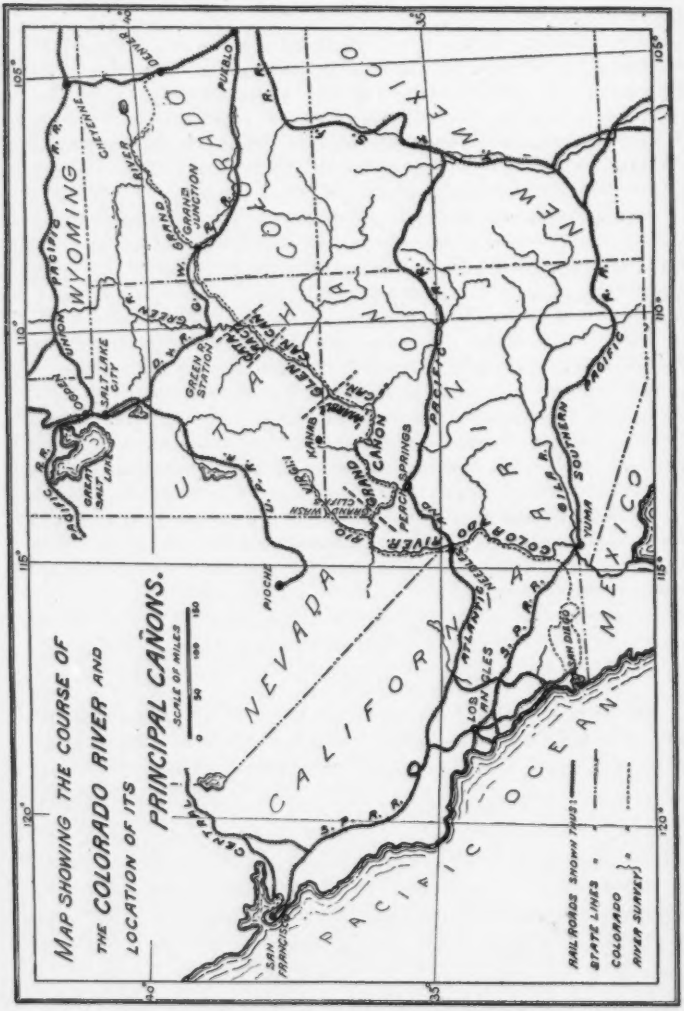
STANTON ON CANONS OF THE COLORADO



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BRICK MANUFACTURE AND BRICK PAVEMENT.

BY F. A. CALKINS, M. Am. Soc. C. E.

WITH DISCUSSION.

PART I.—ELEMENTS AND METHODS.

The art of brick making is supposed to have originated in ancient times with the powerful races found in Egypt, Chaldea and China in the Old World, and in Mexico and Peru in the New. The ruins of buildings and tombs left in these countries testify that they were skillful builders. Rawlinson states that the dimensions of bricks baked by the Chaldeans were 11½ inches square and 2½ inches thick, and those of a later date 13 inches square and 3 inches thick. All are familiar with the Egyptian method of tempering clay with a stick and drying in the sun three thousand years ago. Compare the ancient method with the practice at the present time in any small town where bricks are made, or even at the brick yards on the Hudson; there pug mills will be found in operation which are only a combination of several sticks and a mule; and

green bricks are still dried in the sun the same as was practiced by the ancients, showing little advance in three thousand years.

The first bricks manufactured and burned in this country were at New Haven, Conn., in the year 1650; and the next city to claim early manufacture is Philadelphia, where they were made thirty-five years later, in 1685. The first brick machine of which we have any record was made in Philadelphia in 1840. It was a soft clay machine operated by horse-power. This machine was destroyed in 1844 during a riot, caused by the brickmakers fearing it would take bread out of their mouths. In 1847 a dry clay machine was made in the latter city. That the moulding of bricks by hand can be done rapidly was clearly demonstrated at Cincinnati in 1832. The moulding of nine thousand bricks was then considered a regular day's work. In a contest at this date between two expert moulders, working from sunrise to sunset, one moulded 24 700 bricks, and the other 25 470. A similar number were moulded at a contest in Philadelphia at a later date.

The clays considered in this paper, treated by improved methods, are located in New Jersey and Illinois. The clays of New Jersey were deposited by a glacial drift in the Tertiary Period, and compose a portion of the belt designated by geologists as the plastic belt, which extends from Long Island through New Jersey to Georgia. Near Philadelphia this belt is about 6 miles wide, and of increasing width to the southern portion of Virginia, where it is more than 80 miles wide. It is called plastic, as it is susceptible of being moulded without the admixture of any foreign substance. Most clays outside of the plastic belt originated in the recent or Quaternary Period. The clays of the central and eastern section of Illinois are included in the upper coal measure formation, and the western portion of the State in the lower coal measure.

Constituent Elements.—The properties of clays are modified by composition. The physical structure has weight to determine the quality and density, yet fineness and division of particles are also controlling points. The theory advanced by the late Professor George H. Cook, formerly State Geologist of New Jersey, is the best received at present. He states "that the microscope reveals a crystalline structure which the eye does not detect, and that this structure varies greatly in different samples; some are composed of masses of hexagonal plates or scales piled up in long bundles and masses of unattached scales nearly

perfect. Such clays are always but little plastic, but may become so on mechanical treatment, such as grinding and kneading. On examination after receiving that treatment the clay shows the same elements of structure, but broken and confused, no bundles left intact, scales broken, and a homogeneous mixture of cracked material, still crystalline. Clay beds are found with the clay of this broken up form, still a crystalline mass, and on the degree in which the crystalline structure is retained its plasticity depends." As this examination was made only with plastic clay it does not apply to flint clays.

Professor Edward Orton, in his report on the Economic Geology of Ohio, Vol. V, states that "the mineralogical structure is worthy of consideration as well as the chemical one with reference to their value. The minerals going to compose clay are kaolinite, quartz, mica, feldspar, oxide of iron, lime and magnesia probably as silicates of the alkalies, sulphate of iron, titanate of iron and various rare constituents such as cobalt, copper, zinc, etc.; all of them are not found in each clay. There is no theory worth consideration at present concerning the difference between flint and plastic clays. It is a point in chemical composition, or water hydration, and is, it seems, at most dependent on the physical structure and may be studied with best effect through the microscope." "The impurities most to be dreaded in refractory clays are iron and potash, and it is hard to state which is most to be feared. Iron is not so powerful a flux as potash, which is the worst of all common elements, but the iron is present in larger amounts than potash in most clays, and consequently does as much harm, if not more. If iron is present as the sesquioxide it takes more heat than when in the protoxide state to combine with clay, for iron will only combine with silica in the protoxide state, and if that state is already developed it is easier to combine the sand and iron than if in the oxide. Sulphate of iron has a bad effect on clay, since its decomposition gives rise to a lower oxide of iron. Silicate of iron is also detrimental, since it melts at a comparatively low temperature. Lime and magnesia act as fluxes on clay."

Testing Clay.—In the report of Professor Orton can be found a method of making a chemical analysis of clay that recognizes its physical structure, classifying together bodies that are alike, which will enable a correct comparison to be made. The chemical test should be followed by a microscopic examination of its mineralogical structure. The data thus obtained of the properties of the clay will result in a correct com-

parison of the nature of clays and their value for any use possible. When the tests described are completed they should be supplemented by a fire test to develop points indicated by the analysis to be weak ones. Fire tests are of two kinds; one is to subject the clay to a high degree of heat (without the admixture of any foreign substance), which will develop the quality of the clay to endure heat. The other test is to put the clay through a course of treatment for its intended use, which will decide the fitness of the clay for the purposes intended. If manufacturers would submit their clay to a series of tests of the character described, it would reveal to them the best methods of treatment, and avoid the loss of thousands of dollars caused by the thumb-rule of experiments in general use.

Tempering Clay.—The existing prejudice against bricks made by machinery the author believes to be due to the fact that clay is often taken direct to the machine imperfectly tempered. As a brick machine usually possesses the necessary power to make brick without tempering the clay, some manufacturers neglect it entirely or do it imperfectly. When a broken brick fails to show a homogeneous structure it clearly indicates that a clay has not been well tempered before pressing. There is no necessity for this condition in a machine-made brick, as tempering machines in great variety can be obtained, adapted to every condition. Machine-made bricks from well tempered clay are more dense in their interior than on the outer surface, but when poorly tempered it is the reverse.

There are three distinct processes utilized for treating clay for machine-made brick: the soft mud, the stiff mud, and the dry process. A more uniform nomenclature is preferable; therefore we will designate them as the soft clay process, stiff clay process, and the dry clay process. The tempering for a soft clay and the stiff clay process is identical, differing only in the quantity of water added to bring the clay to the proper consistency, which is variable and controlled by the nature of the clay. Ordinary clay when treated by the soft and stiff clay process is improved by being thrown up and exposed to the rain and frost, or placed in a clay-house and wet, to allow dry lumps to absorb moisture, although Mr. Eudaly says this is not always so. A better plan is to just pug the clay and allow it to lay a few days before using. If not practicable to prepare clay in advance, a granulator and crusher is necessary to thoroughly crush and pulverize all tough and dry lumps. When clay is free from

stone the smooth roll crusher with differential motion is useful, but if stones are present a compound four-roll crusher with top rolls corrugated to remove the stones should be used.

When clay is deposited in a pit it can be handled economically to the machine by means of a conveyor. For the dry clay process it is essential that the clay be of considerable depth, and enough should be hauled under cover to last several months to permit its moisture to become uniform throughout, but it should be dry enough to allow the bricks to be set in the kiln at once. Some clays are found that do not require previous exposure, which will be explained in the description of plants, Part 2.

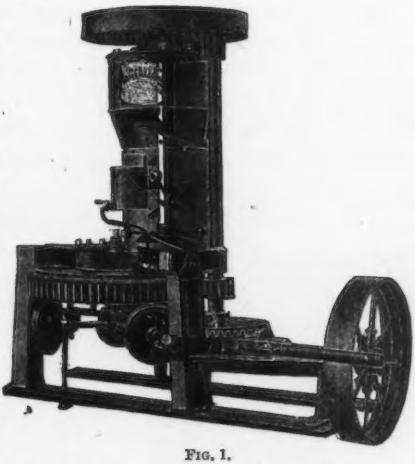


FIG. 1.

MACHINES IN BRICK MAKING.—A large portion of the brick plants operated by modern methods date to a period within seven years. When we consider the accuracy with which a machine works, what delays their exclusive use in brick making? First, it is largely due to cost of modern machine methods. Second, it can be traced to the violation of the first

FIG. 2.

principles of treating clay, either in the use or adaptability of the machine. It is the use of clay direct from the bank, untempered, that has produced inferior bricks, and not the machines.

Machines for treating clay by the stiff clay process are of two types, the mould and the die press. In the former the clay is pressed into steel lined moulds (set in a revolving horizontal wheel) by the action of spirally arranged knives on a vertical shaft (Fig. 1). A follower closely fitting the mould elevates the bricks above the surface of the wheel. The die machines are divided into two classes, the auger and the plunger. The

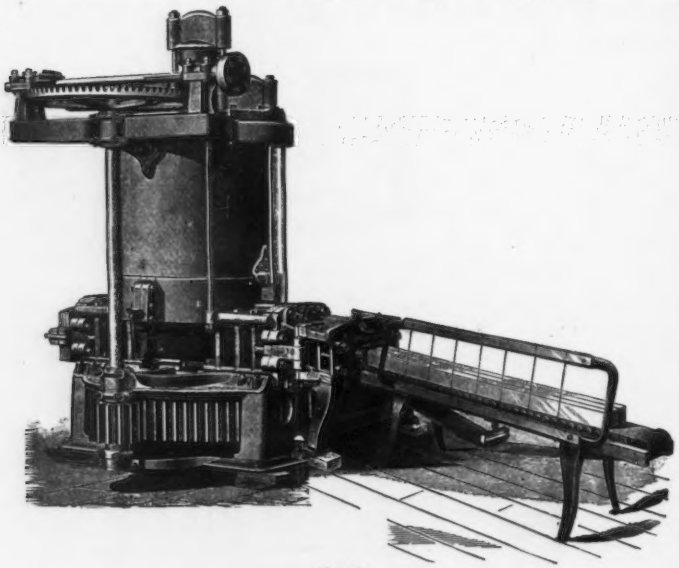


FIG. 3.

clay in the auger type (Fig. 2) is forced through a die by a series of knives arranged spirally on a horizontal shaft. The machine discharges the clay in a continuous bar or bars, permitting it to be cut in sections by steel wires, operated by hand or automatically, cutting the width of a brick and designated as side cut, or, the length of a brick and known as end cut.

In the plunger type (Fig. 3) the clay is forced by knives and a mud ring downward into a chamber from which it passes through the die by the action of a reciprocating piston or plunger. The clay passes from the die

onto a cutting board, where it is cut into bricks by the methods explained for the auger type. The moulded clay on leaving the machine is strong enough to be removed safely with ordinary care. The objections to this method are that when clay is forced through a die it has a grain in the direction in which the clay is forced. If side cut, the grain runs vertical; in end cut, it is in longitudinal layers or laminations, the latter splitting easily, but being difficult to cut crosswise when required in building masonry. When side cut, it is easily broken, but cannot be split. Defects found in bricks by either method have doubtless been caused from imperfectly tempered material, for it hardly appears possible that perfectly tempered material forced into a die would be deposited in layers or laminations sufficiently to diminish the quality, but rather that the opposite effect would be produced, as the great pressure applied would increase the strength and make it more homogeneous. Side cut bricks having finished sides and ends are often utilized for face bricks. The stiff clay process is adapted to prepare bricks and tiles to be repressed for ornamental as well as for plain work. Bricks made by a stiff clay machine are 40 per cent. stronger than hand-made from the same clay.

Die moulding machines have been made of a faulty construction, causing a tendency of the die in some cases to produce seams or laminations in the brick, but this defect has been overcome by lubricating the dies and also by layer forcing propellers, and this has also overcome the curved form in the brick.

Dry Clay Machines.—By this method the clay is tempered by passing through a pulverizer, which reduces it to fine powder. This powder is carried by conveyors to a hopper above the press. Under the hopper is a charger open at top and bottom, which travels forward, receiving a charge of clay from a hopper, and then moves backward, dropping the clay into molds. During each alternate motion plungers descend and press the clay into bricks. After the compression the upper and lower plungers are both lifted upward; the upper enough to permit the charge to pass forward as before; the lower plungers move upward until the top surface is level with a table in which the charger slides. The lower plungers here remain stationary for a short period, until the charger moving forward pushes the bricks off. When the bricks are started off, the plungers drop and the moulds receive another charge of clay. The elements of a dry clay brick machine are the parts for compression, for

charging, the table and the mould box; the plungers, the parts for discharging, the master wheel and automatic cams.

There are two types of machines for pressing dry clay bricks. In one the lower set of plungers remains motionless and the upper does all the pressing; in the other both top and bottom plungers begin to move toward each other at the same time, and although the amount of travel differs, yet the last small space of compression is performed half by each plunger. The latter method tends to preserve the corners of the bricks in a more perfect condition. There is no practical difference in solidity of bricks made by the two types of machines. Fig. 4 shows a dry press utilizing the latter method.

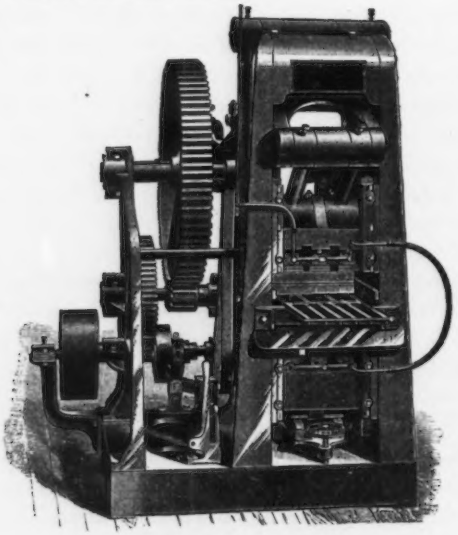


FIG. 4.

DRYING BRICK.—Clay moulded in a dry press does not require any artificial drying, but is removed direct from the machine to the kiln; but a better grade of brick can be made by drying. All clays treated by the soft and stiff clay process are dried after moulding from twelve to forty-eight hours' time, as determined by the quantity of moisture contained in the clay, the quality of the material and the method utilized for drying; and the bricks are then transferred to the kiln.

Only a brief outline of the methods in use for drying will be given.

The hot floor method is in more general use than any other, which is, doubtless, due to the fact that it is less expensive to construct. A hot floor is constructed of a series of heated parallel brick flues; the arches are connected and covered with brick, producing a uniform flat surface on which is deposited a layer of earth 4 to 12 inches in thickness, which is surfaced with one layer of bricks laid flat. The flues are connected with smoke stacks, the number controlled by the dimension of the drying floor. The green bricks are hacked direct from the press to the drying floor, where they remain until fit for the kiln. Coal is in general use for fuel, yet gas and crude oil are utilized also for heating.

By another method plates of iron are used to form the floor, which is heated with hot steam from the engine while running, or from a boiler when at rest. Long flues are preferable, as they produce more uniformity in heat, and there is less danger of checking the green bricks. Some varieties of clay will endure forcing to any extent, while others must be dried slowly at first, at a temperature not to exceed 90 degrees, followed by increased heat. For other varieties the heat must be retained at a uniform low temperature.

In a third method the floors are built in stories and heated by either live or exaust steam. In a fourth method the bricks are hacked on a slated floor which is heated by steam pipes placed underneath, live and exhaust steam being utilized. The fifth consists of a series of brick tunnels permitting cars loaded with green bricks to enter and remain until the bricks are dry, the loaded car being then taken direct to the kiln. The tunnels are heated by steam pipes located either above or below the tunnels. The sixth method is a combination of the drying floor and tunnel system, constructed of iron and heated by steam.

The weight of evidence from successful manufacturers confirms the mechanical and financial success of utilizing artificial heat. When bricks are sun dried the loss during one season is from 20 to 50 per cent., while the manufacturer must cease work at the beginning of winter. But when artificial drying is used, work may continue during the whole season, provided clay has been housed, and no loss or delay at any time occurs from stormy weather. It will cost about five cents per thousand to hack bricks from the press to the drying floor, and one ton of coal will dry five thousand bricks. A green stiff clay brick contains more than a pound of water to be evaporated, and a kiln of bricks would, therefore, require from 16 000 to 300 000 pounds of water to be evaporated; hence

the important fact is developed that much care and attention should be given to drying methods.

SETTING BRICK.—The method of setting bricks in the kiln materially affects the results of burning. The methods described will apply particularly to kilns provided with permanent walls. In an up draft kiln the bricks are set with a wider space between those at the bottom than at the top, but in a down draft kiln the reverse is the rule. By setting them in this manner the draft is increased, thus facilitating the distribution of the heat. Bricks should be set not only to obtain a perfect draft, but also to utilize all the heat possible from the combustion of the fuel, and to leave the least number of marks on them when burned. Ordinarily the space between bricks is 1 inch, but to facilitate the distribution of heat throughout the kiln, the space is increased or diminished to suit the condition of the bricks. The methods of setting are three over three, four over four and five over five. The cost of setting is variable in different localities, ranging from thirty to sixty-four cents per thousand. Three men will set from twenty-five thousand to thirty thousand per day.

BURNING BRICK.—Where improved methods of burning are in use the old style of kiln built of green bricks and plastered with clay on the outer surface to retain the heat, is discarded. Stationary kilns constructed of brick with permanent walls about 2 feet in thickness, are utilized. Another type is the continuous kiln, which is divided into sections, permitting the waste heat in one compartment to be utilized to heat the green bricks in adjacent ones. The principle of the continuous kilns is to utilize the heat contained in the burned bricks during cooling, in partially heating the green bricks set in adjacent compartments.

The initial process in burning brick is the removal of the excess of moisture in the green bricks, which requires a temperature of 212 degrees. This is called water smoking, the time required to accomplish which is from four to six days (being controlled by the amount of moisture the bricks contain), and from three to four days more to complete the burning and cooling. Slow water smoking is considered preferable, as a rapid change in temperature tends to check the bricks. This checking is produced by too rapid drying of the outer surface, before the moisture contained in the center of the bricks has been evaporated. The extraneous water should be driven off before the heat is increased sufficiently to eliminate the combined water. This applies with greater force when much lime is present in the clay.

The draft in common kilns built entirely of green bricks is upward; this is the same largely in kilns constructed with permanent walls. The permanent up draft kilns are constructed with side and end walls 2 feet or more in thickness, but open at top. The kiln is filled with green bricks, and will hold thirty to forty courses in height, of brick set on edge. To retain the heat, the top course is covered with brick bats and imperfect bricks, then plastered with clay. The down draft kilns are provided with a brick roof, and this type may be constructed to permit the up and down draft method to be combined in one kiln; but there is no special advantage gained by this method.

A brick may look well on the surface, but when broken across the center show only a crust half an inch in thickness that is well burned, indicating that the heat necessary to burn a perfect brick was not continued long enough to produce uniform hardness. As nearly all clays will shrink under certain degrees of heat, the surface of a brick, when harder than the interior, permits unequal contraction to take place, and when subject to uneven pressure it is in a condition to break easily.

Bricks moulded by the dry clay process require a longer time to water smoke than if moulded by any other. As the material is subject to greater pressure it is more dense, consequently contains more clay, and will require a longer time to evaporate moisture. A full and free draft is necessary during water smoking. Down draft kilns are preferred for burning this class of brick.

All clays that shrink much in burning possess alkaline salts, and if heated too rapidly before the moisture contained in the center of the brick has been removed, the salts will effervesce; and if the kiln is closed before the salts are oxidized or burnt off, the bricks will become discolored.

Chemical Change in Burning.—The elements of chemical change in burning moulded bricks are: first, complete removal of moisture, which is accomplished by maintaining a temperature of 212 degrees Fahr. several days after the temperature of the kiln has reached this degree of heat. Next, elimination of the water of crystallization, during which the clay becomes rigid, shrinking in volume. After and during expulsion of combined water, the organic matter burns out. Shrinking ceases when all water of crystallization has been expelled up to red heat, yet with increased heat shrinking will continue up to the moment of fusion. Good flint clay containing some sand will lose all shrinkage on being

once calcined at white heat. Some clays possess a very high percentage of silicate of alumina, containing little, if any, foreign matter. Carbonate of magnesia will lose its water of crystallization at as low a temperature as 60 degrees Fahr.; then cold water decomposes it and the result is an insoluble white hydrate in powder, seen on the cracked bricks in the kiln. The temperature required to complete the burning of a kiln of bricks is from 2 200 to 2 600 degrees Fahr., but burners usually determine the degree by the appearance or color of bricks. The degree of temperature applied during water smoking is ascertained by means of a Fahrenheit thermometer; for higher temperatures the pyrometer is the only reliable instrument, yet the latter has only been brought into recent use and by a very limited number of manufacturers.

The present prevailing practice and the tendency to a large increase in the use of improved machinery and methods, is very encouraging to any having an interest in the development of a good brick; this tendency particularly applies to the manufacture as carried on near cities located in the central States. That the thumb-rule and the stick and mule "combine" will soon be relegated to the past, is the devout wish of the writer. This "combine" has promoted the brick industry in the past, therefore deserves a fitting eulogy, then to be silently buried in clay.

Part II.—Plants.

The Lorillard Brick Works, located about two miles south of Keyport, N. J., are among the largest in the United States.

The soil overlaying the bed of clay utilized here has a depth of five feet or more. The company controls 300 acres of land. After the removal of the surface soil the clay is excavated with steam dredgers and deposited on dump cars which are hauled to an incline and there transferred up an inclined trestle (by means of a cable) into the clayhouse. The cars being side dumping, can discharge the clay on either side of the trestle into a pit below, from which two belts elevate the clay to the tempering machine. These belts are 2 feet in width, and the clay is deposited on them by two men stationed at the lowest point, provided with long handled shovels, while a third man sprinkles sand over the clay as it passes him by the forward motion of the belts. All material after leaving the clay pit is manipulated with mechanical power until delivered in the brick kilns to be set for burning, except the cutting the bricks at the press and their transfer thence to the cars. Fig. 5

will show the arrangement of the granulator, crusher, pug mill and brick press.

One man is stationed at the granulator and crusher to remove obstructions, should any occur in feeding. The granulator is similar in construction to the pug mill (Fig. 7), yet is adapted to receive the clay direct from the clayhouse. The belt from the clay pit discharges material into the granulator, which is provided with radiating knives to break up the lumps of crude clay. The granulator discharges the clay at a uniform rate and in a uniform condition into the crusher (Fig. 6).

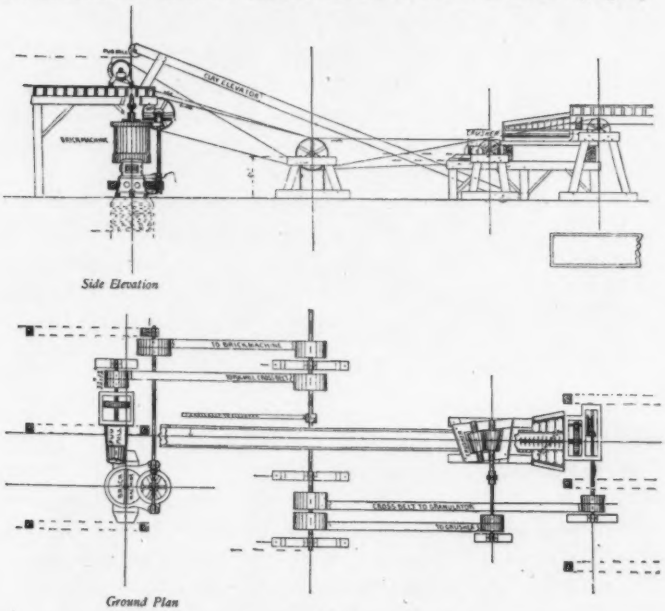


FIG. 5.

At the point of discharge the granulator has reduced all lumps to about the size of eggs, and capable of manipulating enough clay to make fifty to eighty thousand bricks per day.

The crusher is provided with rollers and reduces the clay to thin sheets, which are deposited on a second endless belt utilized to elevate the clay to a height of 14 feet above the floor, there discharging it into the pug mill, located adjacent to the brick machine shown in Figs. 5 and 7. The duty of the pug mill is to complete the requisite tempering of

the clay, reducing it to a plastic mass before it enters the brick press. A pug mill similar in design is now considered an important factor of the

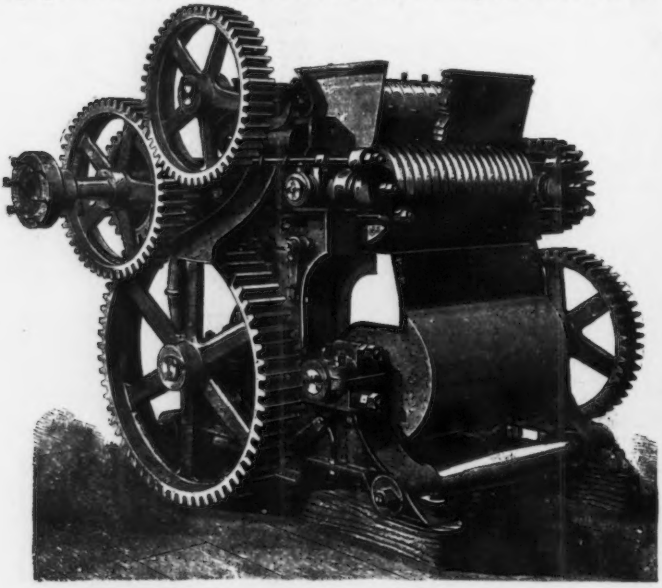


FIG. 6.

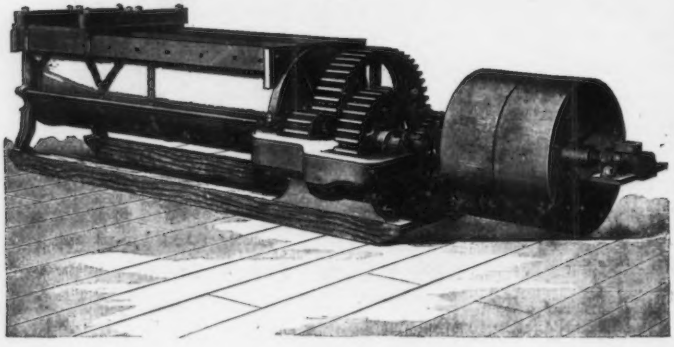


FIG. 7.

success of any well regulated plant. The construction of the pug mill and granulator is similar, both being provided with cutting knives;

but those in the latter are arranged to reduce the large lumps, and in the former to manipulate the material which has been partially tempered by the granulator and crusher, reducing the rolled clay now in sheets to a plastic mass, in which condition it enters the brick machine.

The brick press illustrated in Fig. 3 is of the plunger type in construction. The clay enters the drums or tempering cylinder, in the center of which is a shaft filled with blades that grind the clay and force it through a porthole into the pressing chamber. A plunger driver then presses the clay through the die and on the cut off table, as shown. The mechanical device used to propel the plunger is a steel cam placed on the main shaft between the upper and lower bed plates. It operates the rollers at the front and rear ends of the sliding frame, to which the plunger is attached, providing an alternate forward and backward motion at each revolution of the shaft. Nearly any conceivable size and form of brick can be made by change of die. This press is capable of turning out sixty to eighty thousand bricks in ten hours. The grain of the bricks made by this machine is vertical.

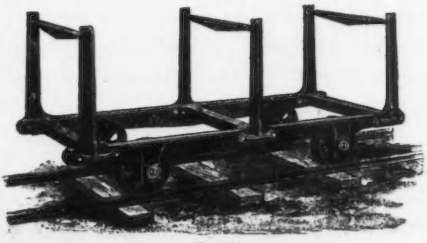


FIG. 8.

At each revolution of the machine the plunger moves forward and forces the bar of clay through the die and upon the apron of the cut off table. As soon as the bar of clay has come to rest upon the belt and the plunger begins to move back, the operator cuts the bricks and removes them with brick forks (which are similar in action to ice tongs), lifting four bricks at a time. Two men operate the cut off device and remove the bricks to pallets resting on the car shown in Fig. 8. The car stands on the side track parallel with the cutting table. Each man is provided with a brick fork, therefore only one motion of each is required to clear the cutting table. Two pallets fill the length of the car, and when covered with brick, a second layer is put in position, resting on the first. This process is repeated until the necessary height is attained, usually six layers. The pallets are placed in position by two boys. When filled, the car of green brick is moved by a man to the main track (who returns an empty car), thence transferring the full car to the drying tunnel.

Fig. 9 shows the side track and transfer car resting on the main track, which supports the drying car shown in Fig. 8, the former illustrating the method of transfer.

The drying tunnel will admit several cars filled with green bricks, which are allowed to remain from twelve to twenty-four hours. When the bricks are dry the loaded car is transferred through the tunnel into the kiln near by, where the bricks are set for burning, which is the second handling after the material has left the clayhouse. The drying tunnels have a clear opening of 3 feet 2 inches x 4 feet, and are about 84 feet long. They are arranged in sections, each section containing from eleven to twenty-five tunnels. This arrangement is made to facilitate communication between the pressroom and the brick kilns, as the latter are located in the rear of the tunnels. Open spaces are left between the sections to permit the passage of carts. The tunnels are heated with

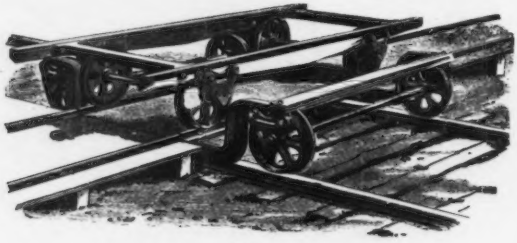


FIG. 9.

steam by means of pipes on the roof, which extend the entire length of a tunnel section, but cover less than half the length of a tunnel. The roof of the tunnels beneath is coated with perforated plate iron, over which the pipes are located and partially covered by a shield.

In order to make the relative location clear, the series of sections comprising the drying tunnels will be represented as occupying a city block, in the form of a rectangle, cut up transversely with alleys between the sections. The tunnel sections fronting on A street, and located on the right side, and the rear or exit of tunnels fronting on B street. On the left side of A street is located the clay manipulator and the brick presses, and the power plant is adjacent for operating them. In A street a track is located from which connection can be easily made to all side tracks leading from the presses and to the drying tunnels as shown in Fig. 9. B street is provided with longitudinal tracks, and tracks connecting with

the drying tunnels and brick kilns. The exit of the drying tunnels is on the left side of B street, and the entrance to the brick kilns is on the right side of B street. The longitudinal tracks on B street extend to the outside of the buildings, and connect with a track leading down to a dock on the bay about one-fourth of a mile distant. At this dock the brick can be shipped for transportation by water. A small locomotive is utilized here to transfer loaded cars to the dock. The works are also connected by rail with the New Jersey Central Railroad. The inner dimensions of the kiln are 25 x 100 feet, with walls 2 feet in thickness, which are open at the top, designated as up draft kilns. They are provided with furnaces on the outside for firing. This plant at the date of the writer's visit consisted of eight kilns, having a capacity of one million bricks each, and four that would contain one-half a million each. The bricks are set in the kiln forty-four courses high, on edge.

Anthracite coal is used for the drying tunnels, but soft coal for burning. The plant has a capacity for producing more than fifty million bricks per annum. The dimensions of the green bricks are 2¼ x 3¾ x 8¼ inches and of burned bricks 2¼ x 3¼ x 8¼ inches, shrinking one-fourth an inch in every direction. Both soft and stiff clay bricks are made at these works. The brick machines utilized here were supplied by J. W. Penfield & Sons, Willoughby, O., to whom the author is indebted for illustrations.

The plant of the Galesburg Pressed Brick and Tile Company is located at Galesburg, Ill. The clay bed is located about two miles east of the city, on the side of a ravine through which a brook flows. A test boring made to a depth of 110 feet failed to reach the base of deposit, the boring having passed through a vein of coal which is utilized for fuel in burning. The common designation of the grade of clay used is "shale," and the deposit belongs to the lower coal formation. The clay bank (covered by a few feet only of soil) consists of a top surface layer, gray in color, and 20 feet thick. Directly beneath this is a bed 45 feet thick of blue clay, which is finer in texture than the gray. Both grades of clay are stratified, the layers being from 5 inches to 3 feet in thickness, and broken by vertical seams. Such seams prevail to a greater extent with the gray than the blue.

The machinery is operated by a 60 horse-power Frost engine. The plant consists of two dry pan crushers, one Andrus dry clay press, one Acme auger press for stiff clay bricks, which include common and

paving bricks. The kilns are six in number, and possess capacity to burn seven hundred and seventy thousand bricks. One kiln with a capacity of burning one hundred thousand bricks is an old style Philadelphia kiln, open at top. There are two square kilns of the Eudaly type, with a combined capacity of five hundred and thirty-two thousand bricks; and three round Eudaly kilns, with combined capacity of one hundred and thirty-eight thousand bricks. The stiff clay bricks are hacked to a drying floor, where they remain one day and are then taken to the kiln. The dry pressed brick go direct from the press to the kiln. The clay being very hard, is excavated with dynamite; and when too large in size for crushers, the pieces are broken up in the same way.

No track is utilized for moving the clay cars from the bank to the inclined plane. The dump cars are provided with wheels having broad tires that can be run easily by one man over the hard surface of the clay pit. The clay cars are $2\frac{1}{2} \times 3\frac{1}{2}$ feet, with the rear end board fitted for self-dumping by a simple device, as the car arrives at the top of the inclined plane. The inclined plane consists of a double track constructed of wood, with a guard strip 16 inches wide in the center between the tracks, and one outside of each exterior rail, which retain the cars in position.

The cars are elevated by means of a winding drum operated from the engine, and deposit the clay into a hopper, which conducts it into the crusher, as shown in plan, Fig. 10. The length of the incline is about 80 feet, and it terminates 30 feet above the clay pit. One man attends two dry pan crushers, removing lumps from the hopper that obstruct free passage to the dry pan. The dry pan crushers (Fig. 11) consist of a heavy upright iron shaft, supported at bottom as shown, and secured in the center of a rigid frame which is about 12 feet wide, with supporting timbers to which the upper bearing of the center shaft is secured. To the upper end of the vertical shaft a beveled wheel 5 feet in diameter is keyed, and over it a driving pulley shaft. The dry pan

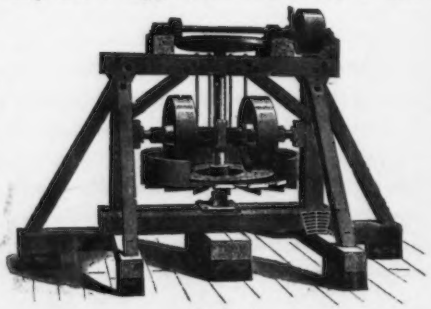


FIG. 11.

PLAN OF PLANT

GALESBURG PRESSED BRICK AND TILE CO.

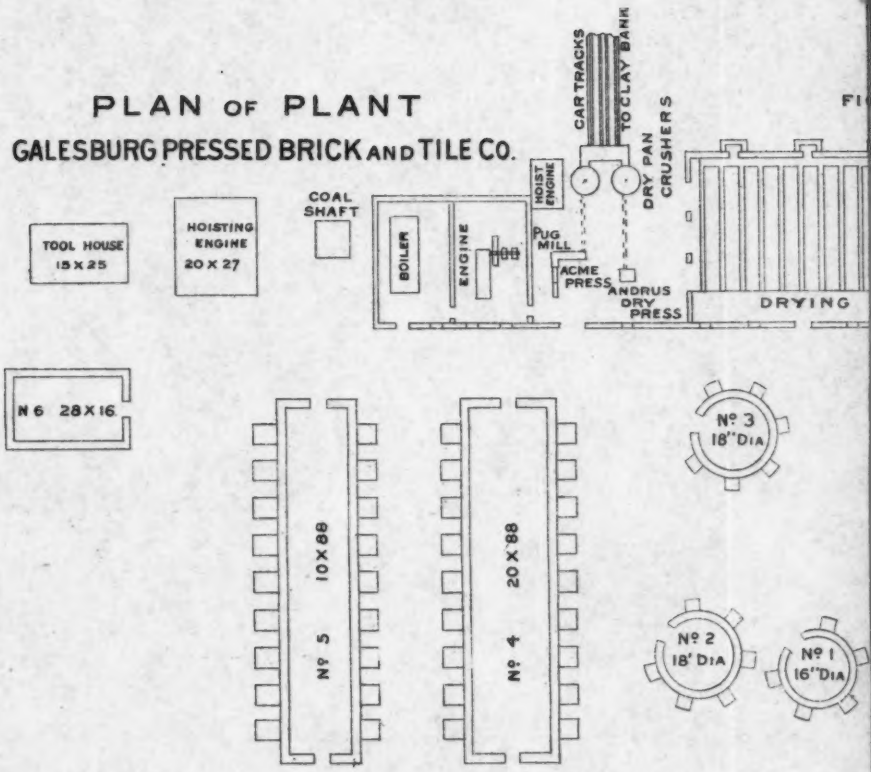
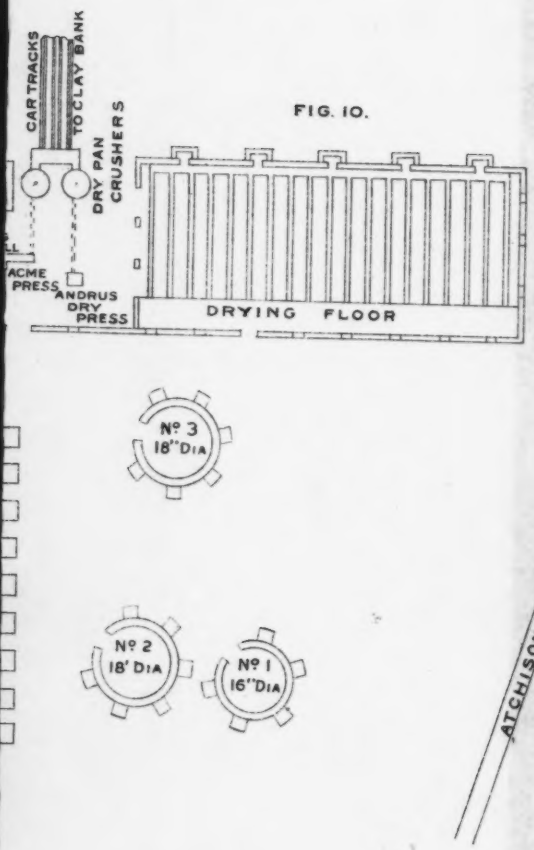


FIG. 10.


CAR TRACKS
TO CLAY BANK
DRY PAN CRUSHERS
ACME PRESS
ANDRUS DRY PRESS
DRYING FLOOR
Nº 3 18" DIA
Nº 2 18' DIA
Nº 1 16" DIA
MAIN TRACK ELEVATED ABOVE BUILDINGS
ATCHISON, TOPEKA AND SANTA FE R.R.

ELEVATED ABOVE BUILDINGS
SANTA FE R. R.

is 8 feet in diameter and secured to a central shaft which is utilized to produce a revolving motion to the pan. Six feet of the center of this pan is solid, around which are set perforated plates 1 foot wide through which the green clay is sifted and falls into a hopper-shaped receptacle below, not shown in the sketch. The cross shaft supporting the rollers is suspended from a cross-head above, thereby removing the entire weight from the pan and central shaft. The space between the pan and the lower face of the rollers is one-fourth of an inch. The pan and crushing rollers are independent. The rollers revolve around a horizontal shaft and not around the pan. This shaft possesses an upward motion permitting large lumps of clay to enter the pan, as the rollers are self-adjusting. When the pan is filled with clay and revolved it produces an opposite motion of the rollers, crushing the clay by a grinding pressure of its weight, which is about 6 000 pounds. Two plows, not shown in the sketch, are bolted to the timber and set in front of the rollers and across the screen plates, in a manner to replace lumps of clay under the rollers again, retaining all lumps in position to be crushed. A vertical rim of boiler plate, 12 to 16 inches wide, retains the clay in the pan. The rollers are 4 feet in diameter and have a 12-inch face. A pair of rollers have the capacity to grind clay to make fifty thousand to sixty thousand common and paving bricks and from twenty-five thousand to thirty thousand paving bricks in ten hours.

Cup elevators convey the ground clay from the receptacle below the dry pan up to hoppers on the second floor, that have the capacity of 4 tons each, from which it descends to a pug mill, which is attended by a boy provided with a hose to add water in sufficient quantity to make the clay powder plastic as it enters the pug mill. This method is the stiff clay process. This pug mill is a trough about 30 inches in diameter and 6 feet long, provided with a central shaft to which the mixing knives are attached. The knives also aid in forcing the clay forward to the opposite end, from whence it drops into the brick press, in which the common and paving bricks are moulded.

A second set of dry pan crushers prepares the clay for the dry press in the same manner as described, and similar carriers transfer the clay to the hoppers and floor above, from which it descends to the dry press without any admixture of water. The "Acme" brick press for treating stiff clay is located directly below the pug mill previously described, permitting clay to drop directly into it through a chute.

The motion of clay in the pug mill is controlled by means of a feed placed in a hopper attached to the pug mill, which is simply one side of this pivoted to act like a jaw, to force the clay against the grinding knives in the brick press, and when drawn back to permit the clay from above to pass freely. The Acme brick press (Fig. 2) consists of a heavy conical-shaped cylinder in which is set a horizontal steel shaft provided with mixing knives, and screw propellers on the end to prevent the clay from slipping back toward the hopper. The ribs (Fig. 12) running around the machine correspond to the threads of a right-hand screw, while the auger acts as a left-hand screw. The spiral ribs prevent the clay from turning with the propellers, moving it forward to the orifice, to which a brick die with two openings is attached, through which two continuous slabs of clay are forced out on a cutting table (which moves on anti-friction rollers) with an end motion of about 8 inches. The cutting frame when depressed cuts six bricks, which are then removed to pallets while the frame is returned to again receive slabs of clay. The green bricks are hacked from the press to the drying floor on spring trucks, where they are set on edge and remain one day, then removed and set in kilns for burning. The capacity of the Acme press is thirty thousand to fifty thousand bricks per day.

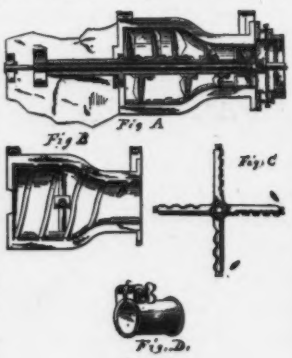
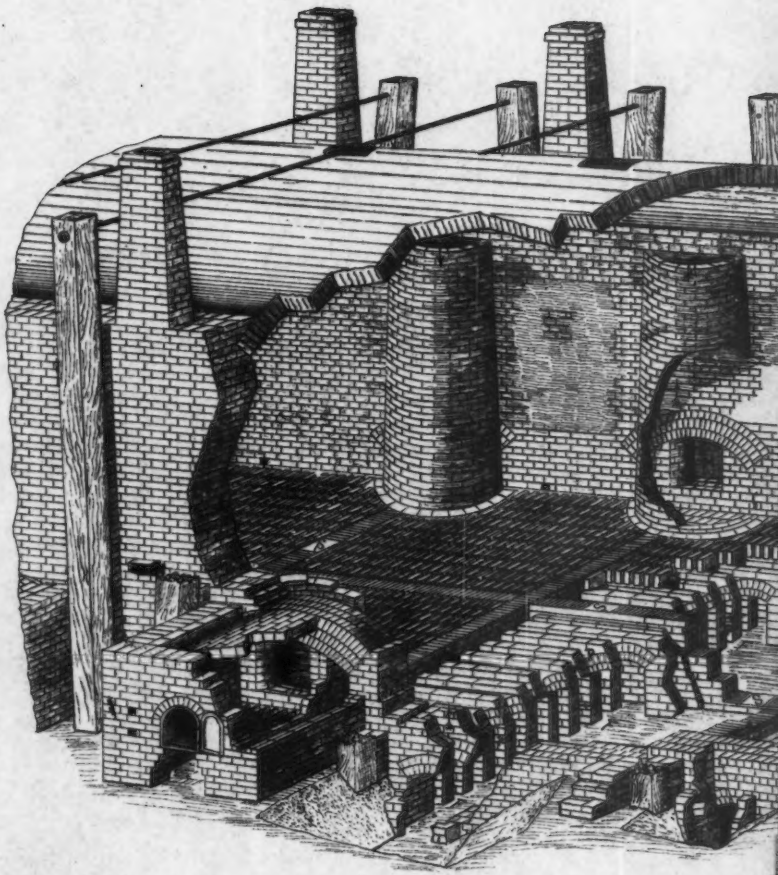
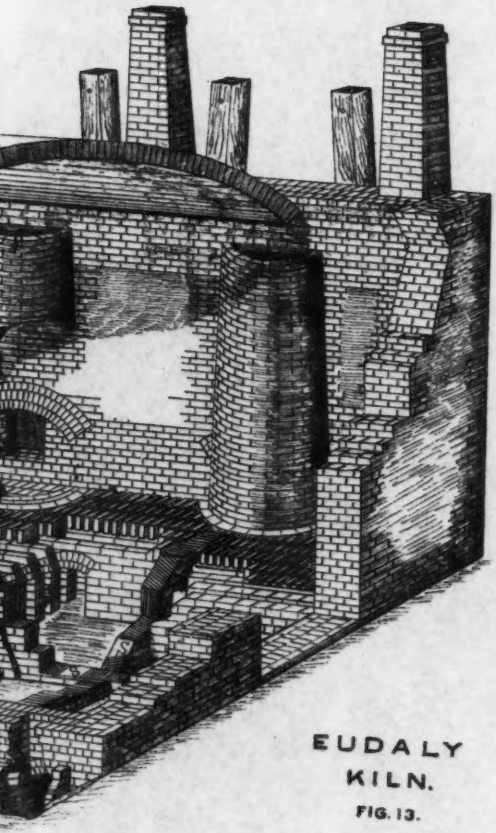


FIG. 12.

The Andrus dry clay brick press, for making dry pressed brick, is shown in Fig. 4. This machine is of a double pressure type (that is, with the plungers having co-ordinate upward and downward motions), with the pressure strains transmitted through connecting rods and not upon the cast iron frame, and with the joints and working parts out of the way of damage from grit. The machine exerts a pressure of about 50 tons on each brick, evenly distributed on both bottom and top of the brick. The pressure plates are adjustable and can be easily raised or lowered if it is desired to change the thickness of the bricks. Clay should be pulverized to the consistency of coarse corn meal before entering the press. The bricks are delivered automatically on the rack in front of the machine at each operation. Two men provided with





EUDALY
KILN.
FIG. 13.

suitable trucks will remove to the kiln twenty thousand bricks in ten hours. Six horse-power is required for operating the machine.

Drying Floor.—The drying floor is located in a brick building adjacent to the brick pressroom and is 44 x 98 feet in size (Fig. 10). The drying floor is on the same level as the pressroom, yet the bottoms of the flues are nearly four feet lower. The heating flues are 36 feet long, leaving a space of 7½ feet for feeding the furnaces. There are nineteen flues in the length of the building, connected with five chimneys by means of transverse channels. The heating flues are higher in rear than in front. The entire floor is covered with earth 12 inches thick in front and diminishing to 3 inches in the rear, and this earth surface is paved with one layer of brick laid flatwise. The capacity is thirteen thousand to eighteen thousand bricks in ten hours. The green bricks are hacked on this floor and usually allowed to remain twenty-four hours, and are then transferred to the kiln. Coal mined on the premises 60 feet below the surface of the clay is utilized for fuel. The coal seam is 30 inches thick. Clay deposit is found below the coal to an unknown depth. A platform 9 feet high extends from the coal shaft to the furnace flues of each brick kiln and also in front of the power-house and drying floor, on which loaded coal cars are propelled by hand to supply fuel.

Brick Kilns.—The location of all the kilns utilized for burning brick in this plant is shown on plan (Fig. 10). All kilns except No. 6 are of the Eudaly type. The rectangular form is shown in Fig. 13. The circular kilns are similar in action, but have a central flue not required in the form illustrated, and are provided with iron bands about 4 inches wide to prevent outward expansion from heat, but rectangular kilns have posts and rods for a similar purpose. The round kilns are better adapted to burn brick in small quantities than the rectangular form. The principles of construction are identical, all walls being two feet or more in thickness and about 14 feet high. The kilns are divided into sections in the bottom only. In each of the sections a large flue *F* runs from the walls *S* to side walls, and there connects with chimneys built in the wall of the kiln. Each chimney has a certain part of the kiln to control, and cannot take heat from any other part, except dampers are closed to throw heat into other sections. These sections being located in the bottom of the kiln do not interfere with setting. A space is left over the wall *S*, when bricks are set, to permit heat to pass quickly down to the bottom of the kiln.

Fig. 14 shows a detail of the furnace. The rear of the furnace is contracted to form a double bell mouthed orifice or throat *M*, flaring at both ends. On each side of the throat *M* are air chambers, *O*, *O*, supplied with air through air flues, *m*, *m*. On each side of the firebox *G* are air chambers, *V*, *V*, supplied with air through flues, *n*, *n*. The air from chambers *V*, *V* and *O*, *O* enters the throat *M* and the firebox through small openings between the ends of the firebrick linings. When the furnace is charged with a fresh supply of fuel the gases set free would, if not prevented, pass out through the kiln unburned, but the currents of air from the air chamber *V*, *V* come in contact with the carbon and hydrogen gases as they rise and combustion begins at once. The light gases not consumed in the furnace *G* come in contact with the bridge wall in the throat *M* in curved lines that first contract and then expand the flame; this increases the draft and at the same time the escaping gases are supplied with oxygen heated to a temperature insuring perfect combustion.

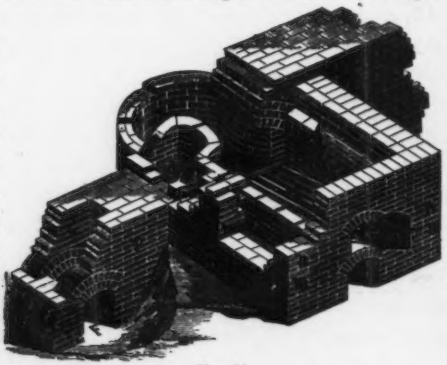


FIG. 14.

The heated air after leaving the furnace flue *M* passes up through an air flue (as shown by arrows in Fig. 10) to the top of the kiln, where it separates, a portion going down through the green bricks to the flues *P* and *F* at the bottom, thence out through the chimneys, while a portion is drawn down through the open space over the wall *S* between the stacks of brick, and distributed directly to the bottom of the kiln. If desired, a portion of the heat from the kiln may be drawn down to the blind flue *F* and allowed to escape from the kiln.

The outer end of the blind flue *F* is closed when burning. The chimney leading from the blind flue can be closed by means of a damper from the outside of the kiln. The center of the kiln being already hot, the heat will continue to pass down the center stack to the bottom, but as the draft is cut off from *F* when the damper is closed, the heat is forced through the openings in the floor to the brick in some other part of the

kiln to escape. This arrangement of draft and flues permits the burner to distribute the heat and thereby prevent an excess at the top of the kiln. Peep holes are provided in each section to enable the condition of the burn to be ascertained from outside. If heat should be found to be excessive in one section, it can be transferred to another by simply closing the damper in the chimney and stopping the draft. This device provides a method of keeping the heat in different portions of the kiln under proper control and preventing excessive burns. When the kiln is cool enough to admit cool air, the flue *F* and holes in the crown are opened, but the dampers in the chimney are closed. The cool air will then enter the flue *F* and pass up through the bricks and out at top. The burner at this plant is one of the best in the country, and the proprietors after several years' experience with these kilns speak in high terms of its burning qualities.

Dry pressed and common brick made here, shrink in burning about one-half inch. Paving brick shrink in length 1 inch, in width one-half inch, in thickness one-fourth inch.

The following named manufacturers supplied the machinery for this plant, and the author is indebted to them for the illustrations and descriptions: Frost Manufacturing Company, Galesburg, Ill., supplied boiler, engine and dry pan crushers. H. O. Whitney, Keokuk, Iowa, the Andrus dry press. Henry Sheckler & Hover, Bucyrus, O., the Acme press. W. A. Eudaly, Cincinnati, the brick kilns.

Part III.—Brick Pavements.

The impression has been general that brick is too soft and destructible a material to endure the rough usage it would be subjected to when utilized for paving a roadway, but tests in a large number of cities in this country, continuing through a period of more than fifteen years, have demonstrated the fact that when paving bricks are composed of suitable material, properly made, burned and laid, they will make a durable pavement.

Quality of Clay.—The material required to make a good paving brick should be a tough, stiff and tenacious clay, which should be thoroughly tempered and moulded by machinery capable of producing heavy pressure to make the material compact, close in texture and homogeneous.

A machine that will make a good building brick is not necessarily

adapted to produce a good quality of brick for paving. It is evident therefore that only selected clay should be utilized, and its quality ascertained by thorough testing before being accepted; and also that machinery adapted for treating this grade of clay only should be used. The best available information obtained by the writer is that a machine suitable for making stiff clay bricks and capable of producing the necessary pressure is suitable to mould paving bricks. Experience may determine that a dry press machine will mould good pavers, but at present it has not been a success, except in one locality, so far as known to the writer. The objection is raised that the great density of paving bricks will have a tendency to retard burning, therefore increasing the cost of manufacture, diminishing uniformity of burning and leaving the center of the brick imperfect.

It is not essential that the clay bear a very high degree of heat, but it is essential that its composition be of a nature to retain its moulded shape, and support the superincumbent bricks in the kiln when in a semi-vitreous condition. The more refractory a clay is, the more it will increase the margin between the semi-vitreous condition and the melting of the clay. A clay that will endure heat and vitrify without melting or running down will make a good paving brick. The admixture of sand to some shale clays will improve their quality for making pavers.

In the plastic clay belt of New Jersey is found a tough quality of clay, between the red brick clay and fire clay. Clays that make the most satisfactory paving brick contain very little sand or surface clay in them. They are generally deep below the surface and are known as shale clays, overlying the coal formations, yet good paving clays may be found in a plastic form. Clays composed of suitable material for making pavers are usually very hard and difficult to grind and temper. Clay that will effervesce when tested with acid indicates the presence of carbonate of lime, which will prevent vitrifaction; hence this quality of clay will be unfit to make pavers.

Quality of Pavers.—A good paver is very dense and absorbs only a small percentage of water. It should be burned to a uniform hardness, and the surface should be vitrified. If water is excluded, frost will be also. The clay should be of a quality to permit a hard burn, yet fire clay is unfit for pavers. As paving bricks are subject to abrasion in a much greater degree than to compression, they should be rich in silica and substances that will readily vitrify. Much iron, alumina and silica

should be present, the first and second to produce strength and toughness, and the latter to facilitate vitrifaction. The green bricks should be dried slowly, with an even temperature, thereby facilitating more perfect crystallization. A good paver should be hard but not brittle nor granular, which will cause it to be chipped and broken easily. After receiving a hard burn they should be annealed to make them tough. Dr. I. S. Hopkins, President of the Georgia School of Technology, states that there are some vitrified bricks which are so brittle that when the wheels of loaded vehicles come in contact with them they wear off very rapidly. These bricks are not good pavers. They must combine toughness with vitrifaction. If a brick is thoroughly vitrified the whole body of clay is melted homogeneously into one mass. Toughness means the tempering which is given to the clay while in the firing or burning process, whereby the life, grain and tenacity of the bricks are not destroyed. The fact that a brick is vitrified does not of itself make a good paver, as there are a large number of clays which will burn to a state of vitrifaction, and yet will not make bricks suitable for street paving because they lack the necessary "toughness."

Shape of Pavers.—It has been proposed that the corners of bricks be slightly rounded instead of square, to prevent chipping, as the sharp corners when broken do not chip evenly, and produce a slight roughness in appearance of the surface. A pavement examined by the writer, which had been in use four years, did not indicate anything objectionable in its appearance or condition. A brick with two round corners would be objectionable on account of increased labor in laying to maintain the round corners on the surface; therefore if round corners were adopted, the four corners should be uniform.

Large bricks, 4 x 5 x 14 inches, have been proposed, and their advocates claim that, if perfectly burned, they will resist greater crushing strain and wear longer under abrasion. But the weight of evidence is largely in favor of the dimension of common bricks. The advantages in using the common size are, the ease with which they are made and the readiness with which they can be obtained, since all brickmakers possess moulds for making this size. Also when pavers are required for repairs they can always be found. All soft bricks unfit for paving can be sold for building, hence the danger of poor bricks being supplied will be diminished. Bricks larger in size will be more difficult to manufacture, slow to dry and more expensive to burn. The drying and burning will

not be as uniform, hence the brick produced will not be proportionately as strong.

A brick slightly warped in burning can be used in the lower course, but only bricks uniform in size and perfect in form and quality should be allowed in the wearing surface. The lower course need not be so hard as those in the surface course.

TEMPERING.—When clay of a plastic nature is refractory it will not easily absorb water in tempering, and if ground before drying, it will be liable to pass through a crusher or rollers in flakes which are not easily broken in the pug mill and therefore may be found in the bricks untempered. If the clay be a shale it is necessary to pass it through a dry pan or other heavy crusher to thoroughly pulverize it, before tempering in the pug mill. When the clay has been well tempered the particles unite closely, and when burned will make stronger pavers, and if broken will present a smooth and glassy fracture. There is a class of clays that will become brittle with much pugging, hence there is a point beyond which they cannot be tempered with safety. They may be dense, but partake more of the quality of glass, breaking easily. The Galesburg clay can be thoroughly vitrified without becoming brittle, and yet be hard enough to resist cutting with a chisel.

VITRIFYING AND ANNEALING.—Experienced manufacturers of paving bricks prefer a kiln in which the heat can be controlled perfectly; therefore permanent kilns only should be used. The burn should be complete when the last fires are built, then the kiln is closed and the heat held from twenty-four to thirty hours to produce a uniform distribution. The cooling of a kiln of brick should then be done by drawing the fires very slowly to toughen or anneal them. Much is claimed for this method, especially for common clays. Some refractory clays vitrify freely by the admixture of an inferior quality of clay, but when used alone become too brittle. Tempering with an inferior grade of clay tends to toughen them. There doubtless may be much good paving material obtained from common clays when the method of treating them is discovered. Some grades of clay, when burned to the vitrifying point, become a solid mass. It is useless to attempt making paving bricks from clays that will not retain their shape under a degree of heat sufficient to vitrify. A hard burned and a vitrified brick differ, as the former may only contain the necessary properties to burn hard, and none to vitrify; then if too hard, it becomes brittle, and chips

easily under travel. Surface clays consisting of decomposed shale will glaze when they contain sufficient iron and silica, but when too large a percentage of lime is present no glaze can be obtained. The term vitrified is sometimes applied to pavers made of fire clay, but fire clay is non-fusible, and fusion is the essential element in vitrifaction.

A few manufacturers are salt glazing their paving bricks, but this method should be condemned, as a salt glaze adds nothing to the strength of bricks, and affords an opportunity to hide defects by filling all cracks, covering blemishes, and also producing an appearance of a hard burn, when the opposite is the condition. A first-class paving clay will contain all elements necessary to produce a glassy appearance without any artificial glaze. The objection will naturally be raised that a brick coated with glass will be too brittle, and unable to endure the concussion incident to heavy traffic; but if the bricks are well annealed after being vitrified, instead of being brittle they will be toughened, and endure concussion far better than bricks that are not vitrified. A perfect paving brick should be hard burned, and then annealed to resist compression and abrasion, and vitrified to resist abrasion, acids and moisture. Vitrified bricks are proof against caustic soda, one of the most destructive chemical agents, as demonstrated by recent experiments, and are therefore capable of resisting all acids affecting a pavement. It is essential that bricks should be impervious to acids as well as to moisture, as the street refuse in cities contains a high percentage of disintegrating elements that often have as much effect in producing disintegration in pavements as either moisture or abrasion; however, all other conditions being equal, brick will outlast all other paving material, and is preferable from either an economic, mechanical or hygienic standpoint. The field for the use of vitrified bricks is not confined to street pavements alone, but they can be utilized to advantage for foundations, sewers, culverts, etc.

Tests and Specifications.—A crushing test of paving bricks made at the United State Arsenal, Rock Island, for Mr. William Steyh, City Engineer of Burlington, Ia., developed the following results, six bricks only being tested, which were selected from those made at three different places. Spawling occurred at from 30 000 to 40 000 pounds pressure on the whole brick. The crushing strength per square inch varied from 4 890 to 9 214 pounds. The weakest sample, that spawled at 30 000 pounds, had an area of little more than 9 square inches. The entire

surface contact of the wheels of a loaded wagon would not exceed 6 square inches, and the weight would be distributed over four different bricks; hence the test for crushing strength appears to be worthless, or useful only for comparing the quality of the bricks.

As the cohesive properties of a paver are the first to demand attention, tests should be made for tensile strength. The maximum loss in paving material doubtless comes from abrasion, due to contact of horses' feet and wagon wheels; therefore tests for abrasion are of equal importance to tensile strain. A test for absorption made by Mr. Patton, of the University of Wisconsin, indicates the following average result: Thirty bricks were selected for testing, obtained from six different makers. The bricks were not subjected to any drying operation before testing, but were kept in a warm room for several days previous to testing. The bricks were first weighed and then laid in a tank of water, the weight being taken at intervals of one hour, one day and one week. The following average results were obtained: Absorption of water in one hour, 0.1016 per cent.; one day, 0.3 per cent.; one week, 0.5177 per cent. Condition of surface not given. An approximate test for absorption can quickly be made by setting a brick endwise, one-half its length in water, and capillary attraction will indicate porosity. Tests for tensile strain, abrasion and absorption appear to be of equal value, but an acid test should not be neglected.

The specifications will necessarily be controlled to a great extent by the method of laying. The quality of brick should be clearly defined, in a manner which will enable the bidder to correctly interpret its meaning. A common clause in specifications is, "the bricks must be of the best quality of hard burned brick." A hard burned brick in one locality may be known as soft in another, therefore this is misleading, as it does not clearly specify quality. The following is a preferable form, the writer unknown:

"The paving brick shall consist of the best quality of sound, hard burned paving brick, made and burned specially for street paving purposes; and should stand all reasonable tests as to durability and fitness to which paving material is usually subjected. All bricks shall be square edged and straight, free from cracks and other defects, of a uniform size and of a quality to be approved by the engineer.

"Three or more bricks of the quality proposed to be used in the pavement shall be furnished with each proposal, the bricks to be labeled

with both the bidder's and maker's name and address, and to be deposited in the office of the Board of Public Works."

A sufficient number of laboratory tests have not been made to establish a standard for quality, but the writer would suggest the following:

First Quality.—The modulus of rupture in compression to be 1 700 pounds per square inch; absorption to be 1.6 per cent.; abrasion under test to be equal to granite.

Second Quality.—Modulus of rupture to be 1 500 pounds per square inch; absorption, 5 per cent.; abrasion not to exceed twice that of granite.

All brick with a variation of more than 15 per cent. below these requirements to be rejected.

An incident occurred at the Galesburg Pressed Brick and Tile Company yard which will show the strength of paving brick. A side track of the Atchison Railroad enters this yard, and several cars standing thereon were loaded with brick. The weight of each car was 32 000 pounds, and the load of bricks 40 000 pounds more, making a total weight of 72 000 pounds for each car. Half a brick was lying on top of one rail as the cars started on a down grade. Two trucks of the first car passed over the brick safely, but as the second car had obtained greater momentum, the first pair of trucks of the second car crushed it.

Methods of Laying.—The tabulated statement showing the detail of methods for laying brick pavements includes all data the writer has been able to obtain as reliable. After excavation has been made for a pavement the ground is generally made compact with rollers weighing about 2 tons, but at Decatur the weight of roller is given at 6 tons. A foundation course of sand or broken stone is spread and compressed by passing the roller over it three times, when the material is made as wet as possible without licking up in rolling, and then rolled until it is thoroughly compressed. The exact form and crown of the finished surface of the pavement is obtained by means of templates for testing the convexity of the surface when grading, and previous to laying the first course of brick. On this foundation surface a layer of brick is laid flatwise, with the longest dimension longitudinal with the roadway. On the surface of this layer sufficient sand is applied to thoroughly fill all joints; then it is rammed or rolled. After rolling, one to two inches of sand is spread to provide a cushion for the finishing layer. On this cushion a layer of brick is set on edge, with the longest dimension across the roadway, which layer is either rolled or rammed.

Methods and Cost of Laying Brick Pavements.

Location.	Method of Preparing Foundation.							Wearing Surface.			Cost.		Remarks.
	Depth of			Brick laid flat lengthwise of street. Broken joints.	Testing.		Depth of Sand.	Brick laid on edge transversely. Joints broken.	Testing.		Per Square Yard.	Price of Brick.	
	Gravel.	Broken Stone.	Sand.		Rolled.	Rammed.			Rammed.	Rolled.			
Galesburg, Ill.	.....	.....	3 inches	do	.....	on 2 inch plank, 10 feet long.	1 inch.	do	do *or*	do	$1 45 to 1 55	$9 00	All labor except curbing.
Quincy, Ill.	4 inches	*or* do	6 inches	do	do	.....	1 inch.	do	.....	do	1 76	7 to 9	Includes grading and curbing.
Bloomington, Ill.	cinders 2 inches	.....	2 inches	do	do	.....	1 inch.	do	.....	do	1 15 to 1 50	10 00	Includes grading and curbing.
Decatur, Ill.	.....	.....	4 inches	do	.....	do	2 inches	do	do *or*	do	1 32, 1 37, 1 40	.....	Includes grading and curbing.
Burlington, Iowa	6 inches	*or* do	6 inches	do	do	*or* do	1 inch.	do	do *or*	do	.....	.....	
Atkinson, Kans.	.....	.....	4 inches	do	do	.....	1 inch.	do	.....	do	.....	.....	
Charleston, W. Va.	.....	.....	3½ in's	tarred board 1 inch thick.	.....	.....	1½ in's	Herring bone style.	.....	.....	1 25 to 1 75	6 to 10	
Peoria, Ill.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1 42 to 1 50	9 50	All labor except curbing.
Jacksonville, Ill.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1 92	.....	
Youngstown, Ohio.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1 73	.....	
Allegheny City, Pa.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1 25 to 1 75	.....	
Nashville, Tenn.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1 80	.....	

After rolling is completed, any broken bricks found are removed and replaced with whole ones. This is done also in the first layer. In some localities in Ohio a foundation is preferred composed of 8 to 15 inches of broken stone, made compact with rollers weighing from 12 to 16 tons, and upon this is spread 3 inches of sand to act as a cushion.

At Nashville, Tenn., pavements are constructed by first spreading a layer of broken stone on which about 2 inches of sand or gravel is spread. Upon this sand is laid the wearing surface of bricks on edge, only one course of bricks being laid. The bricks are common ones, medium in hardness, but prepared by saturating them with a distillation of coal tar applied very hot. A foundation made of concrete will be more rigid than the methods described, but will necessarily be less elastic. It may, however, render better service under heavy traffic. As concrete has not been utilized except to a limited extent, its effect is not known to the writer. Any pavement, whatever material it may consist of, will be more stable when laid on dry soil, brick being no exception; therefore the soil should be underdrained, if necessary, to produce a condition which will materially aid in preserving a uniform surface.

At Galesburg and Decatur the paving bricks are thrown from wagons when delivered on the line of a work the same as paving stone, and only a few are broken.

Crowns.—Gillespie, in his "Manual of Roads," advocates a cross-section of 1 in 40 to 50, and Gillmore, in "Roads and Street Pavements," a section of 1 in 40. Both authors doubtless had in view a street paved with stone, which would permit a crown of 6 inches in a roadway 40 feet wide, and this is ample to turn all storm water into the gutters. As the surface of a stone pavement is rough compared with the surface of a roadway paved with brick, a crown having the same elevation would be too great for the latter. At Decatur, Ill., a crown of 4 inches is allowed in a roadway 50 feet wide, and 3 inches in a roadway 40 feet wide. At Galesburg, the crown of the first pavement laid was one-third inch per foot, but for recent practice the crown is reduced to one-fourth inch per foot, and the section is a flattened segment. The specification states that "the transverse shape of the finished pavement will be a segment of a circle so large that the center of the street shall be 4 inches higher than the lowest point in the gutter, which shall be 1 foot from the outer edge of the pavement, and this outer edge shall be one

inch higher than the lowest line of the gutter." Recent practice, where curbing is provided, is to extend the section to the curb line, omitting any gutter depression. It will be noticed that the experience of several years' traffic developed the fact that a crown of 6 inches exceeded the requirements for a pavement of this character; it therefore was reduced to about 4 inches. As the surface of a brick pavement is comparatively smooth and uniform, without the projecting points always present in a stone pavement, the conditions necessitating a high crown are not present; therefore the writer believes that the practice at Decatur is preferable to that at Galesburg. It may be stated that a perfect surface in a pavement cannot be maintained (therefore the crown should be high to insure removal of storm water), which is true if the pavement has a defective foundation and is imperfectly laid and no attention given to keeping it in repair. Any pavement, no matter of what kind, should have constant supervision, and be repaired as soon as possible when any depression appears, and not left until it becomes a nuisance. The writer did not notice any depression in brick pavements examined either at Galesburg or Burlington, Iowa, that perceptibly affected the condition of the surface. If material removed from trenches is replaced in a dry condition, instead of saturated with water, and thoroughly rammed, there would be no complaint of depression caused from the refilling of trenches. The maintenance millennium for a street pavement will doubtless not arrive until the average plumber is only allowed on a street, when traveling at a speed of 8 miles an hour.

In a climate where frequent storms prevail in winter, any pavement is liable to be coated with mud and ice, and a high crown would have a tendency to contract the width of roadway used on account of the slippery condition of the section near the gutter, and so concentrate travel on the flattened portion adjacent to the crown; but a low crown sufficient to remove all storm water would permit the whole width of a paved roadway to be utilized.

Condition of Pavements.—A brick pavement will present a smooth surface over which heavy loads can be drawn without a jolt, consequently the wear of rolling stock will be diminished, and horses be able to draw from one-fourth to one-third larger loads than over a stone pavement. Brick pavements are easily and quickly repaired. If a soft brick is found, it can be easily replaced. They are less expensive than stone, when durability, wear and tear of teams and vehicles, as well as comfort,

are taken into account. They are as noiseless as a wood pavement, and furnish a sure foothold for horses. The writer has received data regarding this feature in brick pavement from numerous sources where this class of pavement has been in use for many years, and such testimony as to its value is uniform without a single exception, and also that it does not become slippery when wet. Ice does not form as readily as on a stone pavement. The surface of a good paving brick will wear smooth, but does not become slippery. The writer examined a brick pavement in Galesburg which had been in use on a main thoroughfare for four years, subject to heavy traffic, and it remained in first-class condition. The surface of the brick was worn smooth, yet there was no slipping noticed during a visit covering a period of two weeks. The corners were slightly chipped, but not to an extent to affect the pavement. The annexed statement of Prof. Churchill, the City Engineer, relative to its condition is fully confirmed.

Mr. William Steyh, City Engineer of Burlington, Ia., states that if "tamping is done carefully with a rammer weighing 75 to 100 pounds, brought in contact with a plank 2 inches thick, 8 inches wide, and the blows repeated until the rammer rebounds, it gives a satisfactory result, and the bricks will remain in a vertical position, and present an even surface; while, if rolled, they have a tendency to lean in the direction in which the roller is moving, especially if the weight of roller exceeds 5 tons in a width of 4 feet." If a heavy roller has a tendency to incline bricks from a vertical position, a roller weighing only 2 or 3 tons may be preferable. Heavy grades prevail in Burlington, therefore this inclination may be practically due to steep gradients. He recommends that when grades exceed 6 feet in a hundred, a groove three-fourths of an inch in width and about 1 inch deep be made in the bricks, to furnish better foothold for horses.

As the bricks composing the lower course, laid flat, do not require to be as good in quality as the upper or wearing surface, a better selection for both can be made by permitting some rejected brick to be used in the lower course when suitable.

When pavers are the size of common brick, the thickness being narrow and uniform tends to increase the smoothness. The joints between the bricks being one-eighth to one-half an inch, the latter the maximum, little chipping occurs, and when it does the depth is too slight to perceptibly roughen the surface, hence heavy and long continued traffic

does not produce a rounded surface to each brick as is often seen in a stone block pavement. The bricks are laid as close together as possible, therefore it is necessary to use fine sand to brush into the joints.

Mr. E. R. Chatten, City Engineer of Quincy, Ill., states: "I have but one opinion, and that is that when properly constructed with burned brick, or proper materials, it will prove the coming pavement for the West, and equal to anything but granite for heavy hauling." Mr. A. H. Bell, City Engineer of Bloomington, Ill., writes: "I am very much in favor of brick as a paving material when the proper class of brick can be obtained at reasonable rates and the work is well executed. Brick pavements are giving entire satisfaction in our city, and we are using nothing else. It stands the heavy traffic of our city of 25 000 population very well when the bricks are well selected, and better than Joliet limestone or wooden blocks, which are in use on some of our streets."

The economic problem to be solved in a pavement should include maintenance as well as construction, and maintenance is controlled by the amount of traffic; hence the latter is an important element to be considered in determining the economic value of a pavement.

In addition to the gentlemen whose names are given in this paper, the writer would express his obligation to the following: Prof. R. T. Whitfield, Curator of Geology, American Museum of Natural History, New York; T. S. Randall & Co., Indianapolis, Ind.; Galesburg Pressed Brick and Tile Co.; J. P. Hale, Charleston, W. Va.; E. R. Chatten, City Engineer, Quincy, Ill.; A. H. Bell, City Engineer, Bloomington, Ill.; Prof. George Churchill, City Engineer, Galesburg, Ill.; William Steyh, City Engineer, Burlington, Ia.

APPENDIX.

GALESBURG, Ill.,
September, 1888.

F. A. CALKINS.

DEAR SIR,—Our first piece of brick pavement was put in about four years ago. It was very near our railroad depot and a large lumber-yard, over which the heaviest traffic passes constantly. The wear is very slight, hardly more noticeable to-day than when it had been down only six months. There are, unfortunately, some depressions in the pavement caused by a deficiency in making a good foundation. I have this summer taken out bricks from the center of the street to find how much

wear could be seen, and have found the bricks of full width, with the single exception of worn or chipped corners, and this only to a limited extent. One may walk for rods over this pavement and find scarcely a broken brick, and usually that one would show from its light color that it should not have been placed there.

We have quite a long section laid three years ago, which is to-day in as good condition as the day it was finished, only that in the center, where horses travel most, there is a slight chipping of the corners, which hardly ever is so great as to reach the middle line of the brick surface. It is a question whether this chipping of the corners is not a good thing, in that it may afford a better hold for horses' feet.

Our soil is a soft prairie loam some 2 feet deep, lying upon a porous yellow clay. It is absolutely essential that the roadbed be made solid and free from any soft places occasioned by excavations new or old, and when the grading has brought the bed to the exact contour of what the pavement is to be when finished, it should be rolled repeatedly with a heavy roller. When the roadbed has been thus prepared, we spread a layer of good sand over the entire surface from curb to curb to the thickness of 3 inches, and in my opinion the sand should not be dry, but should be moist enough not to run; upon this sand layer a pavement of bricks on their largest surface and their lengths longitudinal with the street is laid, and then the pavement is rolled with a roller heavy enough to settle the bricks thoroughly into the sand beneath them. This lower layer of bricks ought to be about as good as the surface bricks, though many allow a grade slightly inferior to be used. The surface bricks are laid upon their edges, their length transversely of the street; they should be laid as compactly as possible, care being taken to break joints and to keep the courses in nearly a true line across the street. Our bricks are not perfect enough in shape to prevent a sufficiency of sand from entering the crevices to make a solid bed. The pavement thus formed is again rolled, and then dressed with a layer of dry sharp sand, which is worked into any and all crevices by sweeping.

We have used the ordinary yellow clay for bricks, and when these have been well made and properly burned they seem to do well, but they are not equal to the bricks made from a clay we have which looks when in its natural bed like layers of stone. We demand that the bricks be burned to the point of vitrifaction, but prefer that they shall not be much vitrified. Our bricks when thus burned, when broken into small pieces are so hard that they will scratch glass about as a diamond will. So you will see that we have a superior clay for bricks. These bricks are very compact and heavy and take almost no water, and so when wet from rain are not more slippery than other pavements.

We have no stone pavements with which to compare the brick, but we have some stone crossings, and I have never heard any objection to the brick pavement from its slipperiness when wetted by rain or when

frozen in winter. We occasionally have sleet storms here when everything is slippery, but I have never noticed that the brick pavement differs from other surfaces under similar conditions. The street in front of my house has been paved three years, and I have never noticed any difficulty from the surface becoming icy so as to interfere with traffic, and the travel is as heavy and constant as upon any street in the city—a place of about 15 000 inhabitants.

We have had no occasion as yet to make repairs, except when, after a time, a depression in the pavement shows that some old ditch or trench for water pipe, gas pipe or sewer had not been well tamped; such a depression is very easily repaired. From present appearance our brick pavements will not need repairs for a dozen years, if for a score of years. Still, our traffic is not to be compared with that of large cities, where trucks and drays are loaded with many tons.

Our curbing is made in several ways; sometimes ordinary stone curb, sometimes a strip of scantling to retain the bricks in place until the dirt has been thoroughly solidified at the pavement edge, sometimes by bricks 12 x 4 x 5 inches, laid so as to form a gutter, with the blocks sloping from the edge of the gutter up to the grass area and to the ordinary brick pavement. This is for residence property only, where grass areas are made between the street roadway and the sidewalk.

I think I may safely say that our business men unanimously agree that for all our Western cities, where stone and cedar blocks are not abundant, the brick pavement is the thing; and I may say further that the opinion is almost unanimous, that if stone and cedar blocks were abundant, the brick pavement would still be the thing, because of its merits when compared with other materials.

Yours truly,

GEO. CHURCHILL,
City Engineer.

F. A. CALKINS, C. E.,
Ogden, Utah.

DEAR SIR,—From my present experience with brick pavements, I would lay down the following rules for the construction of the same: In the first place, the clay of which the bricks are made should be compact and solid, having enough iron in it to make the bricks tough in addition to being hard. The clay should be pulverized to a fine powder, so that it will make a homogeneous mass when being moulded into bricks. I do not think that pure fire clay is a good material for paving brick, as it does not fuse or melt readily, and for this reason does not become homogeneous, which is the main point of a suitable paving brick. Having secured a first-class brick, we will now consider the different methods of constructing the pavements. According to various published reports, Charleston, W. Va., was the first or one among the first cities in this

country to experiment with brick pavements. This pavement was laid under the following specifications: After grading the street to the proper contour, about 3 inches of sand was spread over the surface, on which were laid inch boards lengthwise with the street, which again were covered with about 1 inch of sand, after which the bricks were laid herringbone fashion. This method has some good points, but also serious objections. Its good points are an even and fairly solid foundation, not too rigid, but elastic enough to make it pleasant to ride or drive over. Its objections are the perishable nature of the boards, and the inconvenience and greater expense of digging up the street for necessary water, gas, steam heating and sewer repairs. It also involves a greater expense in laying the bricks, requiring better skill and more time than if laid at right angles with the street. To use a concrete foundation adds to the expense and is open to the same objection as the board foundation; as regards the necessary repairs of the underground systems, therefore, I should not adopt this method unless there was no other way of securing an unyielding foundation.

As far as I am able to judge at the present time, the specifications used in western Illinois and Iowa have advantages over those just described. In the first place, the use of the lower course of brick instead of boards insures a better quality of bricks for the top course. Experience teaches us, that no matter how carefully the bricks are selected in the yards, before delivery to the work there is always a large percentage of the selected bricks which have to be rejected as top brick, but can be used to advantage as a bottom or lower course brick. If these bricks could not be used in this way, there would be a strong desire on the part of the contractor to put them in, when not too closely watched; but aside from this, the lower course of bricks is far superior to the boards, as the bricks do not decay, while the boards in the course of time will. When compelled to dig into the street for repairs of the underground systems, you do not have to take up a whole square equal to the length of the boards, but only a trench large enough to work in, and should the earth in the trench settle afterward, all that is required is to remove the brick, refill with sand and replace the pavement; this can be done in a very short time at a small expense, which should be borne by the party who caused the digging up of the street. In 1888, when Jefferson street, in this city, was paved, the Water Company put in lead pipe connections at every 20 feet; they put all the earth back in the trenches, rammed them as well as this class of work is generally done; but nevertheless about half of the trenches sunk down during the following winter and spring and had to be raised. This was done by the Water Company and paving contractor jointly, the expense amounting to about fifty cents per trench for both sand and labor, since which time the street has shown no more sinks. In some cities, notably Nashville, Tenn., they have been creosoting the brick before putting them in the pavement, to

make them impervious to water. This would perhaps be well enough, if a paving brick had to contend with water only and not with traffic. If a brick will absorb an appreciable amount of fluid it is not fit for paving purposes, hence the expense of making a soft or porous brick suitable for paving purposes will prove a bad investment. As to filling the joints with pitch or paving cement, to make the pavement water tight, it is a very good feature; but I doubt whether the advantage sought for, equals the extra expense of the first as well as subsequent costs in taking up and relaying the pavement, where necessary repairs on the underground system have to be made. The joints on a brick pavement are so small that it takes rather fine sand to run into them, and after being thoroughly filled with sand, very little moisture will find its way to the foundation. You can take up a section of the pavement after it has been down about six months, and examine the soil under the foundation, and you will find the same perfectly dry even at places that have been soft and muddy before the pavement was put down. The advantages of brick pavements over all others are, cleanliness, moderate first cost, easy and cheap repairs, healthfulness, comfort and durability, always provided you have the proper material. There are lots of brick pavements laid now which will not last very long on account of using an inferior article. Yours truly,

WILLIAM STEYH, C. E.

DISCUSSION.

CALVIN TOMKINS, Assoc. Am. Soc. C. E.—Some time ago I read a paper before the Society upon this subject, treating especially of the methods pursued in the manufacture of brick in the vicinity of New York City. The paper to-night describes methods pursued in the western part of the country with much success. Regarding the relative merits of both methods I would say that those described by Mr. Calkins require more capital and also greater intelligence to operate satisfactorily. Frequent attempts have been made about New York City to manufacture brick as described, but with indifferent success. In the more primitive process as conducted about New York City, the clay and sand are shoveled in approximately correct proportions directly into the brick machine, where they are subjected to pugging, and are then pressed into individual moulds from which they are dumped on the surface of the yard and exposed to the drying action of the sun and wind. When sufficiently stiff to allow handling the brick are hacked up in rows, and after remaining in this condition for a few days are set in the kiln to be burnt, the kiln itself being built up with the bricks that are to be burnt, and plastered on the outside with clay. Regarding the drying of brick artificially, it is my opinion that in this locality not much could be saved by adopting that process, as the loss due to storms and

interruption of labor amounts to less than the increased expenditure for plant, attendance and fuel under the method described by Mr. Calkins.

Regarding the tests which Mr. Calkins suggests could be applied to bricks for paving purposes, I would say that I hardly think that we have as yet arrived at a point in this new use of brick to warrant us in placing much dependence upon any tests other than those resulting from actual use. The very different wearing properties of bricks, which in all respects appear much the same in quality, would indicate to my mind that the only safe test at present is the test of experience. Later on, I think, we may be in possession of more data and a wider knowledge on which to base practical tests for this use of brick.

S. WHINERY, M. Am. Soc. C. E.—A great deal has been said and written in the last few years on the subject of brick paving for streets. And yet it is a subject about which there is very little information of a reliable character from the standpoint of the Engineer. Many of the writers on the subject seem to have been actuated by enthusiasm and a brilliant imagination rather than by the cool teachings of experience. Even the writer of this paper is not free from the extravagant statements that have been so plentifully showered upon the public; as witness his assertion, that "All other conditions being equal, brick will outlast all other paving material, and is preferable from either an economic, mechanical or hygienic standpoint." On the other hand, some of the writers who have decried brick as a paving material, have not adhered closely to the facts, or have based their arguments on the failure of the earlier pavements constructed with hard burned common brick, overlooking the fact that the vitrified paving brick of to-day is as different from its predecessor, as granite is from soft limestone.

The one thing most needed in order to discuss brick pavements fairly and intelligently, is a respectable array of facts gathered from experience and scientific observation. But as the modern vitrified brick pavement has only been in existence for a few years, there has not been time for the necessary facts to be ascertained and accumulated. It may, therefore, be truly said that these pavements are, at the present time, in the condition of interesting and promising experiments. It has been sufficiently proven that the use of hard burned common brick, as a material for street pavements on streets having any considerable amount of travel, will result in failure, and we can safely exclude them from further consideration. The vitrified or semi-vitrified brick made from selected clay of a peculiar quality, carefully prepared and burned, is an entirely different thing, having little in common with the ordinary brick except in name. Considerable areas of pavement made from these vitrified bricks have been laid in many cities of the smaller class, or on suburban streets around the larger cities, but they have not been in use long enough to demonstrate their measure of durability, even under the comparatively light travel to which they have been subjected. A number of such pavements have already failed, but fairness requires the

statement that in some cases, at least, the failure was due to faulty construction rather than to the inability of the brick to sustain the travel to which it was subjected.

In judging of the relative durability of different pavements, it must be kept in mind that the durability of any pavement, the material of which is not subject to natural decay, is measured by the amount of travel it will carry before it is worn out. In other words, it is a question of tons and not of years. The statement that a brick pavement has been in use for a given number of years on a back street in a small city, and is still in good condition, is, therefore, no evidence of the practical durability of the pavement. It is very unfortunate that we have so little data relating to the tonnage of city streets. Captain Green did some valuable work in this direction, the results of which were published in a paper read before the Society some years since. The company with which the writer is connected has for some years past given a good deal of attention to this subject, and has had taken censuses of travel on a large number of streets paved with various kinds of material, in different cities. It is hoped in this way to determine the average life of the various kinds of street pavement, measured in tons of travel per square foot of surface. Until some such standard is adopted, we cannot arrive at just conclusions as to the relative durability of the various kinds of pavement in use, and must expect the confusion of evidence that now exists on the subject.

In reference to the endurance of brick pavements under travel, we have a large amount of fragmentary and conflicting testimony, most of which is entirely without value, because no reliable standard of comparison with other pavements has been adopted. It is not, perhaps, unnatural that the citizens and officials of cities having populations of from 10 000 to 30 000, should speak of the travel on their principal streets as excessively heavy; or that they should believe that any pavement that has stood up under such travel for a few years, has fairly earned its title to great durability. The reputation for durability of brick pavements rests largely on experience derived from its use on streets of the character named above, as the following table will show. It embraces some of the best known brick pavements, about which much has been said and written, and is made from an actual counting of the travel on each street, upon the same basis:

Name of Street.	Kind of pavement.	Tons carried per square foot per day.
Chapline, Wheeling, W. Va.	Brick.	23
Sixteenth, " "	"	18
Franklin, Peoria, Ill.	"	39
Second, Cincinnati, O.	Granite.	196
Race, "	Asphalt.	203
Main, "	"	103
Pennsylvania Ave., Washington	"	65
State, Columbus, O.	Brick.	14
Fourth, "	"	23

A glance at this table shows how insignificant is the so-called heavy travel on these brick streets, as compared with that on the principal streets of a large city, where the pavements are subjected to more tons of travel in one year than the brick streets carry in from five to ten years. So far as the writer is informed, brick pavement has not been tried, except in small sample areas, like those referred to below, on streets having as high as 100 tons of travel per square foot per day. In the few instances where it has been laid in these small sample areas on such streets, it has uniformly failed. Such a sample was constructed on Pearl street, between Race and Elm, in 1885. The best West Virginia paving brick was used, and they were laid on a broken stone and gravel foundation 10 inches in depth. As it was put down as a sample by the contractor, upon condition that if it did not prove durable it was not to be paid for, it is to be presumed that both the material and workmanship were of the best. Under the moderately heavy travel to which the street is subjected, the pavement failed in less than two years, and was replaced by granite. In 1886, the intersection of Washington and Dearborn streets, Chicago, was paved with "Hayden blocks," put down as a sample to prove their capacity to endure heavy travel. In about two years it was entirely worn out, and was taken up and replaced by other material. It is proper to say that the Hayden block is believed to have no superior among the many kinds of vitrified paving brick now upon the market. In 1887 a sample of brick pavement was laid on Winter street, in Boston, Mass. In less than three years it became worn out and was removed. Other facts of the same character might be given, but it seems unnecessary to extend the list.

When a brick pavement shall have endured for five years on a street having an average travel of 200 tons per square foot per day, there will be some justification for the oft repeated claim that brick pavements are as durable as are those of granite or sheet asphalt. At present there is no substantial basis for such a claim. A paragraph in Mr. Calkins' paper illustrates admirably the character of much of the literature of the subject of brick pavements. He states that, "At Nashville, Tenn., pavements are constructed by first spreading a layer of broken stone on which about 2 inches of sand or gravel is spread. Upon this sand is laid the wearing surface of brick on edge, only one course of brick being laid. The bricks are common ones, medium in hardness, but prepared by saturating them with a distillation of coal tar applied very hot." From this the reader would fairly infer that the character of pavement described was a standard one in that city, and presumably used to a considerable extent. The facts are, that in 1885 a pavement of the character described was laid in the intersection of Union and College streets, and was thought to give promise of great success. Two years afterward, two blocks on Union street were paved on the same plan, but, as it soon appeared, in an inferior manner. Both pieces of pavement were quickly worn out and

removed, the first named being taken up in 1888, and the second in 1890; since which time no more pavement of that kind has been laid in the city. Yet the pavement still lives and is doing duty in the literature of brick pavements. While it is preposterous, in the light of present experience, to place brick in the front rank of paving materials as regards durability and other desirable qualities, there can be no doubt that a pavement made with the best quality of vitrified paving brick, laid in a proper manner on a concrete foundation, with the joints between the bricks properly filled with pitch or other water-tight cementing material, will prove reasonably durable and satisfactory on streets having a volume of travel not exceeding, say, 25 tons per square foot per day. It is to be observed, however, that a brick pavement constructed in the manner just stated, is not very much less expensive than one of other materials constructed in like good manner.

In regard to tests for paving brick, I agree with the writer of the paper, that the present methods are not entirely satisfactory. A street pavement is subjected to destructive action by forces which combine the effects of crushing, abrasion and percussion. Of these three, percussion is undoubtedly the most destructive element. Compared ton with ton, the writer is satisfied that the destructive effect of horses' feet on any pavement is at least three times as great as that due to the action of the wheels of vehicles. If this be true it must be at once recognized that a test for resistance to percussion is of the greatest importance; but so far as the published tests show, this element has been neglected, except in so far as the usual "tumbling" test embraces it. In this connection it is somewhat singular that both the English engineers and Captain Green, in their censuses of street travel, excluded the weight of horses in computing the tonnage of travel.

T. C. Clarke, M. Am. Soc. C. E.—I am pleased to hear that Mr. Whinery confirms my own idea—that the wear of brick pavements comes from the chipping of the edges of the bricks.

The proper test would be to strike such bricks as the inspector would select on the edges and corners with a light steel hammer. They should be able to bear the same blow as a granite block.

Edward P. North, M. Am. Soc. C. E.—Mr. Clarke's proposition for testing paving materials by striking them with an edged tool, seems to me an admissible one, particularly when applied to granite, sandstone and brick, as it is nearer the test given to those materials in every day wear than many now proposed. All blocks laid in pavements are injured by the percussion of the horses' hoofs and of the wheels when falling, from the roughness of the pavement, and by the grinding of the heavily loaded wheels. Both of these tend to cleave the blocks; a tendency greatly increased by the unnecessary widths of the joints allowed in this country. Mr. Clark's proposed test would enable an engineer to judge quickly and easily of the cleavage resisting qualities of the stone or brick offered.

Mr. Whinery's mode of keeping accounts of traffic may not be quite as good, as he would only count the collars, *i. e.*, the number of animals employed in draft; apparently thinking that a rapidly moving, lightly loaded vehicle is as destructive to a road surface as a heavy load moving slowly. In the case of the Macadam roads this is undoubtedly correct, as the springing of light wheels is effective in dislodging stones.

The value of hard paving brick as a substitute for stone has not been noticed. In many instances they might make an economical and efficient substitute when either concrete or the stone of this country is too friable for the wear they are likely to meet. At the Manchester Ship Canal the dock walls were of concrete for about 25 feet, or to the water line, where a band of granite about 8 inches deep was laid, projecting about 4 inches from the face. From this fillet the concrete was faced up to the granite coping with Staffordshire "blue" bricks. From breaking one of these I doubt if they are as strong and tough as our paving bricks. Mr. Knott, the manager for the contractor, told me they were abundantly strong and tough for the position they occupied.

S. C. Thompson, M. Am. Soc. C. E.—I have had considerable experience with brick in sewer work. On one contract, in the Twenty-third Ward, I was obliged to condemn large quantities of brick on account of the impossibility of cutting them either across or splitting. The bricks were tough and of good shape and hardness, but appeared to have had the center forced from the machine in advance of the sides, so that when an attempt was made to cut them they would break like an inverted U. These bricks were made in New Jersey, and were of a special brand. This brand was machine made, and appeared to have been made from clay that was not uniformly tempered. Another brand made by the same company, said to contain 25 per cent. of sand, did not exhibit these peculiarities, but was easily cut in any direction.

Alfred Francis Sears, M. Am. Soc. C. E.—This paper of Mr. Calkins treats very fully of the modern methods of manufacturing bricks, of the improvement in their quality and the increased diversity of uses to which they are now applied. He has touched briefly on the ancient history of the brick, which he finds to have existed, like the craft of the smith,

> "Since the birth of time,
> Throughout all ages and nations."

It seems to me the time is opportune, as well as the occasion, for placing on record a historical fact, or two concerning not so much the manufacture as the use of brick among a people whose civilization was destroyed by the ruthless conquest of Pizarro. Mr. Calkins' paper mentions Peru as one of the countries making and using brick in ancient times; how ancient we are unable to say, but certainly before the advent of the Incas, for we find among the ruins of those, who recognized the God Pachacamac as the supreme Deity in the pre-

Inca days, large towns surrounded by walls of unburned brick of symmetrical figure and uniform size, and built up in houses of the same material. Mr. Squire's last volume on Peru gives some interesting, and, as I can testify, very accurate sketches of these walls.

I propose, however, to confine what I have to say to the construction of an important historical road built by the Incas for the comfort of their journeys from the mountains, where they had their capital, to the sea-coast near the mouth of the Santa River, which was, I believe, the northern border of their conquests on the coast, and was a favorite place for the royal baths in the warm seasons. You have no difficulty in tracing this road in some parts of the Valley of Samanco and along the plains of Chimbote to the pavilion at the river. It has been described by some writers, and I believe Squire is one of them, as a "double road," *i. e.*, two roads side by side of unequal widths, and both walled in by adobes. This, however, is a mistake, as several members of the Society can testify. There are really three roads running side by side, of which the middle one seems to have been the principal and is nearly 100 feet wide, the edges of which are marked by walls of unburned (adobe) brick, built to a height, so far as one may judge from the ruins, of 3 or 4 feet, and 1½ to 2 feet thick. This road was paved with adobes of similar form and dimensions, and was flanked on either side by an unpaved road of about half its width, which was also protected from the open pampa by a wall similar to those already mentioned. The pavement in the lower pampa has been generally worn away, but up in the Samanco Valley I found considerable sections in quite perfect condition. This is accounted for by the use made of the lower road for the modern passage of cargo mules, horses and donkeys, while up in the valley it seemed essential to select easier grades for these animals than the Inca road afforded, which has thus escaped destruction. I suppose this middle road to have been for the exclusive use of the Inca's palanquin and his suite, and that the peons who carried him and his nobles were barefooted or wore a simple undressed sandal. The llama of the mountains evidently did not travel this road. The flanking roads are generally reputed by oral tradition to have been used by the armed body guard attending the Inca-monarch in his journeys.

I wish to especially invite your attention, as constructing engineers, to a point that was to me the most interesting in these and other similar walls left by the Incas and their predecessors, and that is the fact, that although the brick were made of uniform dimensions, being about 18x 10x2 inches, and laid up carefully with reference to horizontal and vertical lines on faces and quoins, I have never been able to detect a system of breaking joints. Of course, by the accidents of laying, joints were often broken, but you found nothing like a system as it is now known. You will often see joints running from the bottom to the top of the wall and never an attempt at a coping. But after the wall was built the faces

and top were covered smoothly with a stucco of mud. Generally the courses were continuous in horizontal lines, and laid in about 2 inches of mud or wet adobe. At the coast end of these roads there are some interesting works. First, there is a ruin testifying to the former existence of a small town, built, as all the ancient Peruvian houses were, on sand hills or other eminences too high to be reached by the irrigation waters, which gave value among that laborious people to every square yard of land accessible to their vivifying influence. Then, on a lofty hill close at hand, the topmost peak is covered by an elaborate fortification of dry wall in stone and adobe; and third, more interesting than all, is the ruin of what was evidently a pavilion, and contains the only remains of round columns I have ever seen or read or heard of in Peru.

It is a remarkable fact that all their columns were either pilasters to buttress walls, or if detached were of rectangular section. But here is an adobe platform nearly or quite 200 feet long and 25 feet wide. Along each side at the uniform distance of perhaps 15 feet are the bases, I may rather say the stumps, of what were once round columns. These stumps are weather worn; rather by the wind than any other element, as rain is known in that region only once in seven years. They now show a bottom diameter of less than 18 inches and in a height of 3 feet end in a blunt point; generally they are not more than 1 or 2 feet high. But what interested me was the fact of their being built up of adobe bricks laid like the walls on beds of mud. You detect this construction by breaking them off and thus exposing the interior, for the effect of weather wear has been to so dress off the outside as to have them smooth and apparently homogeneous or monolithic, if I may say that of masonry in adobe. The Incas, I judge from these columns, must have had a method of moulding round brick.

While these statements are of no practical use in the modern manufacture of brick, I trust to their historic value and interest, to justify me in laying them before you and asking for them a place in the archives of this association of constructors.

R. H. Thurston, M. Am. Soc. C. E.—I have read Mr. Calkins' paper with much pleasure, and am particularly interested in what he has to say about the use of brick for pavement. It would seem to be important that some further experience be had in the larger cities, under the heavier traffic that is usually met with there. I was in Rochester a few days ago and observed that East Avenue, one of the principal and finest avenues in that city, had been laid with brick, while the principal portion of the city, where the work was not very heavy usually, however, had been laid with asphalt. I am told that the asphalt interest is strong there, while that promoting the brick is weak; but I presume it will be easy to get the facts relating to both, after a little while, when the service shall have revealed their wearing power as compared with the more common pavements. A careful inspection of the two pavements

gave me a very favorable impression of both for light traffic; but I could form no idea of their actual or relative value under heavy loads and a dense traffic. I hear excellent reports of the brick pavement in Western cities; but I have received, and get from Mr. Calkins' paper, no very definite quantitative measure of the value or endurance of the material, and no knowledge at all of the precise qualities, as to strength and toughness, which make the best brick for this work.

This seems to me to be the essential information. No engineer can intelligently advise for or against any given manufacture of brick until he can have a definite specification for the quality that is desirable. Presumably a brick may be burned so hard as to be too brittle for the purpose; and, on the other hand, it may be too soft to have any commercial value at all for this use. Just what are the best combinations of strength and "*resilience*" seems to be still unknown. This is the very first thing for the makers to ascertain, and to present to the engineer, before offering brick for paving purposes. I imagine it will be found that some clays are capable of making admirable paving brick, while others, excellent for building, may have no value at all and may be entirely incapable of exhibiting that wearing power which is required. It may fairly be presumed also, that a brick which may prove best for a country village may be entirely unsatisfactory in a large city or under very heavy traffic. The figures given on page 390 of the paper are good so far as they go; but we need vastly more. The compression specification proposed seems to me to admit so weak a material as to make it useless for the purposes of a contract. I think it will be found that, at many kilns, the weakest "sammel" brick turned out would pass that test, so far as strength is concerned. The absorption test may prove all sufficient and the abrasion test seems to me extraordinarily high and inconsistent with the compression test. It would seem to me that a double test, by crushing under pressure in the testing machine, and crushing by the blow of a stated weight and height of drop, would cover the requirement. The former might, it would seem, be easily established, the latter would require careful experimental investigation to get the proper figures of weight and height.

Modern machine-made brick are, I think, usually much stronger than the hand-made brick of years ago, when the specifications assumed that their maximum strength would range from 3 000 to 5 000 pounds per square inch with the best makes. The latest figures that I have obtained for the best makes have been astounding, when compared with these. Years ago, I tested a brick for Mr. Haswell on which we were able to place about 10 000 pounds per square inch, and I have since tested still stronger specimens. We have recently tested brick, made near Ithaca, New York, of two varieties; of which the common samples bore from 8 000 to 11 000, and the "repressed," about 15 000 pounds per square inch before final crushing. They cracked at from 3 000 to 5 000,

splintered at from 6 000 to 8 500, in the first class, and the two critical periods were reached with the "repressed" article at 12 230, and 14 800 pounds, respectively. They weighed about 125 pounds per foot, the repressed running up to 137. They are usually of a reddish cream color, and very smooth and regular in form.

But this is insignificant beside figures recently given me by a maker of terra cotta in Central New York, who has shown me samples which have stood, in 2-inch cubes, about 40 000 pounds per square inch. I imagine these are ideal materials for paving, and there is no reason why we may not expect to find at various points about the country, equally good clays. The costs of manufacture are not, in any important degree, greater with good than with poor clays, and it should be possible to make brick of these clays possessing enormously high powers of resistance to dead loads and to the blows of heavy traffic.

WILLIAM STEYH, Burlington, Ia.—The tests for crushing strength of paving brick, referred to by Mr. Calkins, were made at my request, at the United States Arsenal, Rock Island, mostly on account of determining their resistance to traffic, or rather to see what weight would be required to crush them, as it was claimed by some people that no brick could be burned hard enough to prevent its crushing under a heavy load. The bricks in question were tested on end, by a misunderstanding, instead of on their edges as they are laid in the pavement, and therefore did not show their true crushing strength by at least one-half; however, it was shown conclusively that it would require an enormously heavy load to spawl or crack them. I agree with Mr. Calkins as to this test being insufficient to determine the necessary qualities of a good paving brick, and that tests for abrasion, absorption and tensile strength should be made, as well as an acid test; but the facilities for such tests are rather scarce in most localities, and even where samples have been subjected to all these tests, it must be remembered, that the samples are generally selected with care, and that their qualities are in the majority of cases, above the average. It therefore depends very largely on the ability, good judgment and honesty of the inspector, whether the specifications are complied with or not. Any one who has had practical experience in this class of pavements will agree with me, that it is not so very easy to distinguish a good brick from a poor one, as an overburned brick will appear all right outside, while it is brittle and porous inside, and consequently worthless as a paving brick. On the other hand, a well burned and tough brick may appear soft, on account of its pale color, and probably be rejected, although it might stand all the tests quoted above. As it is out of the question to subject all the bricks, or even a small portion of them to the various tests, some way should be found by which an inspector may be guided to detect the poor ones. This can readily be done in the following manner:

First, have the bricks dumped or thrown from the wagon when

hauling them to the line of work. Second, if a brick should be rather pale in color, or not as heavy as the average (which is the case with an overburned brick), drop it flatwise on another brick set on edge, from a height of 4½ to 5 feet. Third, immerse it in water and notice if air bubbles appear on the surface, if such is the case the brick is porous, and should it absorb an appreciable amount of water it should be rejected. Any brick that will stand the above simple tests is acceptable, and a pavement laid with such material will stand the heaviest traffic if supported by a suitable foundation.

At the time I wrote to Mr. Calkins about the requisite qualities of clay for paving brick I had no knowledge of the true composition of the clay used in the manufacture of paving bricks for use in this city, and on a superficial examination of the same was led to the belief that it contained iron in sufficient quantities to make the brick tough. This conclusion was erroneous in so far as it is not iron but alumina which produces this result. The following is an analysis, made by students of the State University at Iowa City, Iowa, under the personal supervision of C. D. Jameson, Professor of Engineering:

Silica	77.40
Alumina	11.74
Ferric Oxide	3.29
Potash	3.76
Magnesia	1.91
Lime	1.60
Soda	0.47
Mn. (trace with Fe O.)	
	100.17

LEWIS KINGMAN, M. Am. Soc. C. E.—I have read carefully Mr. Calkins' paper on "Brick and Brick Pavement." There are so many methods, machines and kinds of material that it is not strange that the bricks made, vary greatly as to quality and finish. It is true that great improvement has been made in the methods and machines used during the last seven years. It is also true that as the uses of brick have been widely extended, people buying them have been educated and taught by experience the difference between good and bad brick, and now demand better results than the present methods and machines give them. So long as there is a demand for a poor quality, so long will careless, indifferent manufacture continue.

Here, in Topeka, the making of vitrified brick for street paving was commenced in the fall of 1889. A Penfield plunger, with a capacity of 40 000 a day, and five Eudaly down draft kilns with steam dry houses were set up. They have made 7 540 000, which have been accepted and laid in the pavement of our streets, under my personal direction; during this time, about one-half of the brick delivered for paving have been re-

jected. The plant was supposed to have a capacity of 40 000 bricks in twenty-four hours, but it has not been worked up to more than 25 000 or 30 000, with the average somewhat below these figures, and then one-half of the product was not fit to be used for the purpose intended. The machine broke down more frequently than was expected. Contracts for paving were delayed more than a year on account of defects and weakness of the machinery and the inability of the company to make good brick. The machinery is now worn out; the rollers are concave, so that the material is not ground fine, and the company have had it all taken out, and propose to try another Penfield machine of the auger style with dry pan crusher.

It is not very encouraging for a paving brick company to make brick and have one-half of them unfit for use. Of those made here during the last two years probably 5 per cent. were rejected and broken in two on account of a core or air hole, due to the faulty plunger movement of the Penfield machine. Some of the cores do not appear on the outside, and doubtless many of them have been received and put into the pavement. The brick made by the auger machines do not have this defect. A small per cent. of the brick have been rejected on account of their becoming warped or twisted after leaving the machine—some few more due to the inattention of the cutter leaving a broken end; but the principal cause for rejection is that they have not been properly burned.

The Eudaly kiln used here will receive 160 000 brick. They are well made kilns, tight and about perfect. When the kiln is filled the two ends are bricked up and plastered. Wood is used for from two to four days to heat them up gradually, then bituminous lump coal is used, and the whole kiln kept at a high heat and held at this heat for four or five days, or until the top of the brick in the kiln has settled about 2 feet. It has been found that the application of the heat is the all-important detail in making vitrified brick. The toughness and temper of a brick requires that the dried clay be heated gradually and never allowed to chill until it attain a point past the cherry red, tending to white heat. It must be held at that heat three or four days and then gradually cooled, which takes five or six days. There have been more bricks spoiled from changes in temperature after the fires were started than from all other causes together. I think cold air has too easy access to the flues when the fires are out or low. Some kilns have been spoiled so thoroughly that the bricks were like dried clay, without any ring, and of a dull, dirty color, and not fit for any use. There have been but few bricks spoiled from overheating, when it has happened some of the bricks would run or melt and stick together, but otherwise would be of good quality.

I have known this plant to deliver three kilns, one after another, with over 90 per cent. of them first-class, good brick; then following these good brick would be one or two very bad kilns. This uncertain

risk is one of the details of brick burning that ought to be obviated. It is something that with the present methods seems almost impossible to prevent. That intelligent men, with their money at stake, cannot remedy this seems improbable; yet it goes on from month to month, and people buy and use for other purposes those brick which will not do for paving brick.

Brick pavement has been tested here since May, 1890. Since then there has been laid 73 000 square yards. I think it has met with the approval of our people, but there are many things about it that are not altogether satisfactory to an engineer—so long as the brick are each and every one first-class, well tempered, tough and well vitrified, the pavement is without fault. When a kiln has been properly handled and 90 or 95 per cent. of all the brick are first-class, then it is an easy task to inspect and have good pavement; but when one-half of the kilns burned have been chilled or otherwise spoiled (and it has happened that whole kilns have been), then it is that the inspector has trouble. After they have been laid and traveled over and the "skin" worn off, and a large number of worthless brick found in the pavement that ought not to have been there, this is annoying at least. Until the science of brick-making is advanced so that each and every kiln can be burned and tempered exactly right and all the brick come out good and true, we have not much to boast of. I have used St. Joseph, Mo., Atchison Soldiers' Home, and Osage City Brick here during the last two years, and I am satisfied that all have the same or about the same trouble in burning vitrified brick.

HORACE M. MARSHALL, M. Am. Soc. C. E.—Inasmuch as the author concluded that, "the test for crushing strength appears to be worthless, etc.," it is surprising to see the requirement. "The modulus of rupture in compression to be 1 700 pounds per square inch;" more especially as the said bricks would stand several thousand pounds before beginning to crush. Transverse strain or cross breaking is probably intended, but if so, why not prescribe whether laid flatwise or on edge when tested? No method for abrasion test is suggested, though there seems to be great diversity and want of accuracy in the usual tests, that is, Prof. Ira O. Baker so thinks. His pamphlet, "Brick Pavements," covers much of the subject in very close agreement with Mr. Calkins. If bricks undergoing the abrasion test were clamped at one end of a "rattler" box by some device like a printer's form, so they would receive blows from the shot on one face or edge, while they were themselves supported at back and sides, the conditions would more nearly approach the actual facts in a pavement. From the size and weight of the shot, the length and the number of turns of the rattler, a fair comparison could be made between the impact in the test and in a roadway. With bricks that resist abrasion as well as granite, a pavement should be possible which would outwear granite, for it could be laid smoother. Judging from the table given, the builders of brick pavements never read what Mr. Clemens

Herschel, M. Am. Soc. C. E., wrote on road foundations. On page 20 of his prize paper, "The Science of Road-making," he says: "The foundation to be solid, unyielding, porous and of large material." Again on the next page: "The point never to be lost sight of, is that this foundation course must remain porous, must be pervious to water so that all rain water that soaks through the top covering will find, through it, means of escape to the ground underneath; thence, according to the nature of the subsoil, it is either left to soak into the ground, or must be further led away by appropriate drains." Brick pavements without foundation may be good, but with a foundation they should be better.

Why a roadway should ever have its surface conform to a circle is one of the things past finding out. If the slope near the middle is sufficient to cause the water falling there to flow off, why then should the slope be increased towards the sides? The rational form for drainage would be two planes declining from the median line, say 1 in 300, but as the angle along the intersection of the planes would be objectionable, it should be rounded off with a curve whose radius is practically 900 feet, so as to be tangent to the planes about 3 feet from the median line. If a gutter is desired, make it an invert and round off the edge where it joins the plane of the roadway.

William C. Jewett, M. Am. Soc. C. E.—Mr. Calkins' paper on brick is certainly very interesting and instructive to the members who are using large quantities of brick.

The work of arching the tunnels on the Cincinnati Southern Railway has been in progress for a number of years under my supervision as Resident Engineer. I have made it a rule to insist on the use of the very best brick to be found in the market independent of the usual tests for strength; and the difficulty of securing suitable brick for this work is apparently increasing within the limits of a reasonable haul, including Cincinnati and Chattanooga. A short tunnel is the most trying place in which brick can be used, and unless the bricks are perfect they will ultimately fail through the action of frost. Brick-makers do not like to assort brick and it is rarely that a kiln can be found that will furnish brick for this work without thorough culling. I attribute the difficulty of securing perfect brick in this section to the recent introduction of machines described by Mr. Calkins as the auger type. The bricks from these machines are usually perfect in form and pleasing to the eye, hence they find a ready sale among builders, but the internal mechanical structure is not adapted to durability, at least such is the case with those that have come under my observation. I have no doubt but that the cause of this trouble is as Mr. Calkins says, the improper tempering of the clay, but even when apparently perfectly made I find that they are not equal to those entirely free from a laminated structure. I have used large quantities of brick made with these machines, but the most rigid inspection has been necessary, resulting in constant contention between

the inspector and the contractor, the latter knowing that the particular brick rejected would pass inspection for any other work.

STEPHEN L. HAIGHT, M. Am. Soc. C. E.—In connection with the subject discussed by Mr. Calkins, I would like to call attention anew to the use of the bricks made of furnace slag for paving streets, as there is a superabundance of such material. I saw them in use in Toronto some time since, where they were laid between the rails of a street car line. There was a conspicuous absence of grooving by the horses' feet, such as could be seen where stone blocks had been set in other parts of the same line.

The City Engineer stated, in reply to the objection that they would be slippery and cause frequent falls of horses, that no trouble had been experienced from this cause. A remedy for this danger could be readily obtained by forming grooves in them when they are manufactured.

The weight of such blocks might be an objection to their use at long distances from the place of manufacture, but if properly set they would be much more durable than either brick or stone.

ARTHUR N. TALBOT, M. Am. Soc. C. E.—The subject of paving brick is one of growing importance, especially in the prairie portions of the country where stone of any kind is not to be found. The improvements in the manufacture of brick within the past ten years, and experience with brick pavement extending in two cases over fifteen years with results that are certainly satisfactory for what may be termed the experimental stage, show that where suitable clay may be found, brick constitutes a durable, economical and desirable paving material for light and medium traffic, and also for moderately heavy traffic when best "pavers" are used. But it must be borne in mind that satisfactory results will be obtained only with brick of suitable clay, properly burned, and that such bricks are entirely different from the usual building brick. Some discredit has been thrown upon brick pavement by the use of improper material. The effort to utilize and stimulate a local industry, however desirable in itself, may lead to the acceptance of unsuitable brick.

The absolute necessity of a high quality of brick makes the need for definite specifications more urgent. "The best quality of hard-burned brick," or even the added "shall stand all reasonable tests to which paving material is usually subjected," does not express any definite requirement. Any structural material subject to wear and needing strength, toughness and other qualities should have careful and precise specifications. Imagine structural iron or even cement, especially if manufactured by small local companies, having such vague requirements. Nor does the furnishing of six samples and the requirement that no brick shall be inferior in quality to the samples, obviate leaving the acceptance to the arbitrary judgment of an individual.

How, then, to specify the requisite toughness, hardness and imper-

viousness is an important question. Of the various tests, those of specific gravity and crushing strength are unnecessary. A mixture of rock with clay may increase the specific gravity without adding to the value of the paving brick. Experiments have shown that crushing or pure compressive strength is not conclusive evidence of toughness; and, besides, this test involves greater care and labor and more extensive appliances than the others. High transverse strength has been found to be an attribute of the paving brick which have stood the test of time. This test may be easily made, even if a testing machine is not at hand, as follows: Caliper the plunger of a hydraulic press, such as may be found in the machine shops of any city, and attach a pressure gauge. Place the end of the plunger against a knife edge (easily cast), resting on the middle of the brick. Then the brick may rest on two knife edges placed for uniformity 6 inches apart and the stress of the plunger may be applied. After finding the pressure of the plunger, the modulus of rupture is easily calculated. For ordinary climatic conditions with the pavement subject to repeated freezing and thawing when wet, the absorption test is an important one. Even where porous brick have been used for sidewalks, subject to comparatively little wear, the surface has rapidly disintegrated from the effects of frost, and for pavement, brick must be impervious enough to prevent this action. These two tests of transverse strength and absorption are simple, and quickly and easily made. The value of the rattler test has been questioned, but, while it does not give the same wear as the pavement is subject to, it does give a comparison between the brick and some standard stone, and so adds to the knowledge obtained by the two preceding tests. The grinding test seems less desirable.

The specifications for first and second quality given by Mr. Calkins, are practically the same as those first proposed by Professor I. O. Baker. It would seem to the writer that the requirement for absorption in the first class are more severe than necessary, though if it can be obtained the life of the pavement will be increased. Pavement made from the second quality has given excellent service in our smaller cities. I should, however, suggest the selection of a certain number of brick with every given quantity delivered, say two to every 10 000, which should be tested as above. In the event of failure to fulfill the conditions a further selection and test should be made before rejecting the lot. In addition, any suspicious lots should be tested. The various tests will train the judgment of the inspector, so that inferior bricks are quickly detected. The above tests refer to top brick. Those for the lower course need not be so strong and tough, but should pass a high absorptive test. The application of systematic tests to paving brick will tend to raise the standard of the product and methods of manufacture, as it has that of cement, iron and steel.

By GEORGE W. RAFTER, M. Am. Soc. C. E.—Mr. Calkins' paper is

of interest and value, not only for the information in relation to recent processes of brick manufacture, but, more especially, because of the discussion on the use of brick for street pavements, as such discussion is likely to be productive of great good. The demand for a satisfactory paving material is great in those regions of the West where stone suitable for either block or macadam paving is in many localities entirely wanting. The use of wood has nowhere proved to be economical.

The absence of stone of all kinds for long distances in Illinois and neighboring States is a thing which, to be appreciated, must be seen. For example, on the Cairo Branch of the Illinois Central Railroad, built in 1879, suitable stone for ballasting can be obtained at only two points in a distance of 364 miles between Chicago and Cairo. At that time brick pavements were just coming into use in Bloomington, Decatur and some of the other interior towns of that State. The early brick pavements were mostly poor affairs, but the improvements since made in processes of manufacture, burning and selection of bricks and in methods of laying have greatly increased their wearing qualities.

In regions where what may be termed normal paving material is difficult to obtain, necessity has thus developed in brick a material fairly suitable considering the special conditions there existing. It is not creditable, however, to the sagacity of many of our urban communities that the commercial spirit has led to the use of brick in places differently situated, where better material could be had, and where, if ultimate durability is taken into account, such use can only lead, so far as we now know, to a relatively speedy removal and a greater ultimate expense.

However, in many Eastern cities, where pavements and other street improvements are paid for by local taxation, the struggle of the pavements is fully on. Such taxation carries with it in the cities in New York the right of selection by the taxpayers of the pavement to be laid, and as a result the paving interests maintain an agent in nearly every town of any considerable size. These gentlemen are all alert, each thoroughly posted as to the merits of the wares which he is charged with selling, and each makes it a point of special merit that he is on terms of amity with as large a number as possible of the taxpayers of every street which it is contemplated, even remotely, to permanently improve. Under the influence of the active canvassing which results, the people of the prospectively improved street divide into several parties, each vigorously advocating such form of pavement as accident, self-interest, or friendly feeling for a paving company's representative happens to dictate. Very rarely is the question of ultimate economy considered other than remotely.

In a case which the writer noted not long since, petitions to the Common Council were in circulation for the following pavements: Medina sandstone, three different varieties of sheet asphalt, block asphalt, brick, cedar block, and two forms of Telford roadway, making

nine in all. In at least one case on the street in question the discussion became so warm that two life-long neighbors were only prevented from coming to blows by the interposition of mutual friends.

At the present time eight varieties of pavements are in use in Rochester. Their designations and the approximate cost per square yard are indicated in the following statement, the prices there given including also the cost of all necessary excavation and foundation. In the case of the asphalts and brick the price further includes the cost of repairs for a term of years:

	Per Square Yard.
(1) Medina stone pavement, costing from	$1 75 to $2 25
(2) Trinidad sheet asphalt pavement, costing	2 75
(3) Sicily rock asphalt pavement, costing	2 75
(4) Vulcanite sheet asphalt pavement, costing	2 75
(5) Block asphalt pavement, costing	2 65
(6) Brick pavements, costing from	2 25 to 2 50
(7) Telford pavements, costing from	1 00 to 1 25
(8) Telford pavements, with gravel superstructure instead of broken stone, costing from	90 to 1 00

Of these several pavements it may be stated that the Medina sandstone is the natural material for heavy traffic in this city. The maximum development of this stone occurs at Albion, 30 miles west, on the line of the Erie Canal, and water transportation enables the rock to be laid down at a nominal cost during the navigation season. Sand for the foundation is obtained within or near the city limits, and there is no rational reason why the City of Rochester should ever go abroad in search of a fairly durable pavement material for its business streets. The price of $1.75 to $2.25 per square yard, as given in the foregoing, is the present ruling figure, the range in price being chiefly due to the local accidents of varying distances for hauling material by team, labor, etc. Quality of paving material has also, to some extent, an influence on the price.

While I refer to Medina sandstone as the normal material for pavements on streets with heavy traffic here, I do not wish to be understood as claiming for it superiority over granite and some other forms of stone block pavement, which, however, are not entirely available at Rochester by reason of long haul. My point, so far as I make one, is that by reason of its accessibility the Medina stone is the natural material, and durable pavements for heavy traffic can, all things considered, be procured here cheaper by its use than in any other way.

The price of $2.25 per square yard as a maximum, however, procures a pavement which, under the traffic of ordinary streets, will, with moderate expense of annual maintenance, show a life of nearly thirty years, at the end of which time the blocks will be so nearly worn out as to require entire renewal, which may ordinarily be accomplished, inas-

much as the sand foundation is already in place, for about $1.50 to $1.75 per square yard.

It may be reasonably inferred from the foregoing that the Medina sandstone pavements used here are of the second class, that is, they are laid on sand foundations rather than concrete. Thus far no first-class stone pavements with concrete foundations have been put down in Rochester. Such pavements are hardly suited to streets which have not, in the matter of the various necessary underground conduits, reached what may be termed a fixed condition, the frequent cutting through of the concrete foundations being relatively a more serious detriment to the pavement than the removal and replacing foundations of sand. Medina pavements are mostly used on the business streets, and all these may be considered as to the present time, subject to more or less pulling up. For instance, it is contemplated to build on the line of the chief business streets during the coming season, new sewers much deeper than those now existing, the new sewer construction to be followed probably by the putting down of permanent first-class pavements on the two streets in question. The asphalt and brick pavements now in place in this city are on the contrary on streets where fixed conditions may be considered as existing, and on which there is therefore no objection to making a permanent concrete foundation.

On the proper solution of questions of the nature of the foregoing will depend to a great extent the quality of the pavements in any town which has reached approximately the finished state.

The Telford pavement, as used in Rochester, has little to recommend it. The only available material is a hard limestone which is still far short of furnishing a satisfactory roadway. As constructed here these pavements have about 10 inches of supermaterial, and under ordinary traffic wear down to the substructure in from three to five years.

At the present time there are no wood pavements in use in the city of Rochester, all having been replaced with other material a few years ago.

Medina sandstone pavements are objected to for residence streets on account of the noise made by passing vehicles, and in Rochester as elsewhere, a demand has arisen for a noiseless pavement on such streets. For this purpose asphalt has been largely used during the last few years, and brick are now being introduced for a like purpose. On residential and suburban streets with light traffic, probably no very serious objection to such use of the better quality of paving brick of recent manufacture can be made, though before adopting them largely, even for light traffic we ought to know more of the wearing and lasting qualities of the material. To adopt them for the principal business streets of a city of the size of Rochester, especially one with large iron or other manufacturing interests, involving much heavy drayage, would be an exceedingly bold departure. Mr. Calkins, while expressing the opinion, based

on experience, that bricks composed of suitable material, properly made, burned and laid, will furnish a durable pavement, is still unable to give any definite statements of their relative efficiency in comparison with other paving materials under like conditions of use. This lack of definite information on a vital point, cannot be charged, however, in any degree upon the author of the paper. The responsibility for it, must be put largely upon the indifference of the street maintenance departments of our municipalities.

In illustration of the importance and value to an urban community of definite information on the question of relative costs of maintaining the different kinds of pavements, I present a tabulated statement of the first cost of pavements of all kinds, including the Telford as laid in the City of Rochester in the 10 years ending April 1st, 1891. The figures given are the totals of the final estimates for each year, and include the cost of curbs and such other accessories as are usually constructed in connection with permanent improvements, as for instance, additional surface sewers, lot laterals and manholes to sewers, the cleaning of sewers, etc., and in the case of the asphalt pavements the cost of extending water services to the curb for all vacant property. All these various items over and above the cost of pavement proper, may be taken at about 15 per cent. of the whole. On this basis the expenditure for pavement proper for ten years may be stated for even figures at $1 500 000.

TABLE SHOWING THE COST OF PERMANENT STREET PAVEMENTS IN THE CITY OF ROCHESTER, N. Y., FOR TEN YEARS. ALSO THE POPULATION BY YEARS FOR THE SAME PERIOD.

Final Year. April 1st to April 1st.	Medina Stone.	Asphalt, all kinds.	Brick.	Telford, all kinds.	Totals.	Cost of Repairs of Improved Roadways.	Population.
1881 to 1882.	$60 151 23	.....	.....	$76 804 97	$136 956 20	.....	*93 100
1882 to 1883.	25 772 70	.....	.....	69 415 76	95 188 46	.....	95 650
1883 to 1884.	51 602 31	.....	.....	60 728 23	112 330 54	.....	99 850
1884 to 1885.	36 882 85	.....	.....	6 117 33	43 000 18	.....	104 200
1885 to 1886.	.....	$27 000 00	.....	.....	27 000 00	$14 405 95	108 500
1886 to 1887.	23 396 89	97 681 19	.....	14 887 59	135 965 67	28 937 64	113 900
1887 to 1888.	113 405 45	117 889 99	.....	86 779 03	318 074 47	20 960 03	119 700
1888 to 1889.	7 341 39	16 100 00	.....	55 777 21	79 218 60	12 939 25	126 500
1889 to 1890.	86 950 03	172 341 36	.....	58 650 24	317 941 63	11 596 63	132 000
1890 to 1891.	116 185 78	210 289 36	$58 843 89	24 173 83	409 492 86	16 696 05	138 000
Totals....	$521 688 63	$641 301 90	$58 843 89	$453 334 19	$1 775 168 61	.....	.....

* Official population in 1880, 88 366; in 1890, 133 896. No additions to territory.

As to the relative cost of maintaining various classes of pavements in the City of Rochester, practically nothing is known. Beginning with the year ending April 1st, 1886, some attempt has been made to show the total cost of repairs to all kinds of improved roadways, but even these

statistics have not been kept in such manner as to inspire much confidence in their accuracy. So far as the writer is informed, aside from the year ending April 1st, 1886, no attempt has been made to separate the items of cost of repairs for the different classes of pavements, which is really all that is valuable in statistics of this character. As they stand, however, they make a strikingly elegant edition of the play of Hamlet with the moody Prince of Denmark absolutely left out.

It seems to the writer, however, so self-evident a proposition as to require no special proof of its reasonableness that in any city where an expenditure of $1 500 000 is made for paving materials and labor in ten years, that some little attention to relative values might be paid, as will be noted on inspection. During the past ten years the use of asphalt has begun in Rochester and has already so extended as to make a very large percentage of the total of pavements laid during that period. During the last two years brick has fairly gained a foothold, and present indications are that its use will be considerably extended in the next few years. In the meantime, definite information as to the permanency of the different grades of brick used for paving is greatly lacking. This fact was very forcibly impressed upon me on reading the discussion a few months ago of the question of paving brick at the meeting of the National Brick-makers' Association of Zanesville, O. The gentleman opening the discussion, Mr. Jones, said in effect that any good building brick clay would make, by proper treatment, a good paving brick for light travel; but that for heavy traffic a semi-fine clay or some of the shale clays should be used. The next speaker, Mr. Shea, took issue with Mr. Jones on the question of quality of clay, his view being that fire clays are to be avoided. Mr. Tiaffny, who spoke later in the meeting, expressed strongly the opinion that a clay, suitable for sewer pipe, would make a good vitrified brick, his view being clearly that some degree of vitrifaction was essential to a durable paving brick. On the question of vitrifaction the views of the manufacturers were equally at variance, as indeed might be expected, the quality of vitrifaction being a function of the clay. Mr. Beattie held that the ideal paving brick should be impervious to water and stand immense pressure, and stated that brick manufactured by his firm at Atchison, Kansas, stood 12 000 pounds to the square inch. He also stated as an additional necessary quality that paving brick must possess toughness in conjunction with vitrifaction. Mr. Ittiner, referring to the material in the vicinity of St. Louis, stated that vitrifaction was an injury to the clays found there. Mr. Tiffany, speaking to the question of vitrifaction, said it was a matter of experiment and trial with different clays in order to determine the quality of clay best suited to produce a paving brick which will answer all the several requirements.

On the question of absorptive properties of brick Mr. Calloway stated that he had in the exhibition-room a brick made on a soft clay

machine that was thoroughly vitrified, and would stand 90 tons pressure. He offered to donate $10 000 to the Association if his brick showed any absorption after twenty-four hours' immersion in water. Messrs. Beattie, Ittiner and Purrington were all of the opinion that brick would eventually supersede all other forms of paving and Mr. Ittiner expressed the opinion that all present would live to see granite taken up and brick put down in its stead.

My purpose in giving the views of the several leading manufacturers as briefly abstracted in the foregoing, is to enforce the following points:

(1.) The manufacturers differ widely, not only as to what constitutes the ideal paving brick, but as to the best method of producing it. The statement of Mr. Tiffany that it is a matter of experiment and trial in each case probably represents the real state of the matter.

(2.) It is apparent that the present product of paving brick must vary considerably in different localities, some, undoubtedly, being far superior to others. In the absence of definite standards of quality, and with the strong commercial competition existing, it is clear the consumer has, as usual, to bear in many cases the burden of proving by actual experience the essential worthlessness of the inferior varieties.

If brick paving is really a legitimate competitor of granite and other first-class paving material, and has come to stay in that character, it is submitted that the manufacturers can very well afford to expend enough in the way of concerted scientific experimentation to remove from the subject the conflicting and contradictory views which now so extensively prevail. Independent of the greater probability of the consumer getting the worth of his money which may be expected to result from such work, there is a commercial side to the transactions, to the benefit of the manufacturers themselves. Brick pavements are, in this city, like asphalt laid with a guarantee of all repairs on the part of the contractor for a definite term of years, and probably the same condition is exacted elsewhere. The removal, by actual demonstration, of the uncertainty as to the wearing quality of brick, which now largely exists in the public mind, may be expected to operate to the advantage of the manufacturers, not only by entirely doing away with the time guarantee, but by leading to an increased use of brick for paving purposes.

In order to indicate some of the lines which such an investigation of the new paving material may reasonably pursue, I submit herewith, without comment, two self-explanatory letters published in "Paving and Municipal Engineering," for February, 1891.

Editor of Paving and Municipal Engineering:

In response to your call for suggestions in regard to a uniform scheme of thorough tests of paving material, I would submit the following for testing stone (natural or artificial), and brick:

1. In compression—stress being applied continuously and gradually.
2. By concussion—by dropping weights upon them. This test

would determine their brittleness and their power to resist sudden shocks.

3. Porosity.

4. By Hacking.—In this test I would use some means of cutting the brick or stone, with some instrument of about the same degree of sharpness as a common trowel, a weighted knife dropped a known distance and determining its action, and number of strokes necessary to cut a certain amount, would be a very important test. One of the most worthy tests, being easily and quickly made, is to take a sample and hack it in two with a trowel. If it scales and splits off you may know that it will act the same way under traffic, and a little practice will soon enable you to determine its relative hardness and toughness.

5. Grinding on stone to determine its toughness.

6. Polishing.—Determine the angle of friction between a sample and steel or iron, and then after rubbing two samples together a stated time under known pressure, determine their angle of friction, which would show their tendency to polish.

7. Tumbling—by putting samples in a cylinder with sharp castings and determining their loss.

8. Determine the relative "noisiness" of samples by laying the material in the same manner as laid in the pavement and dropping steel or iron weights on them and measuring the distance the concussion can be heard.

These tests would, I think, about cover all the essential tests, unless it would be the "freezing," which would hardly be practical. The bicarbonate of soda test might be applied, but would hardly justify the undertaking.

HIRAM PHILLIPS, C. E.,
Eng'r Dep't Mo. University.

To the Editor of Paving and Municipal Engineering:

GENTLEMEN,—Accepting your invitation to submit practical tests for paving, permit me to suggest the following: That at Indianapolis six blocks, or six divisions, of equal length, aggregating twelve hundred feet, be selected by the committee; place upon the whole a uniform foundation of limestone macadam, or limestone Telford, or limestone native cement Beton, or limestone Portland cement concrete, or limestone Portland cement concrete interlocking, double-lever press blocks, as the committee may select.

On division "A," pave with granite-quartzite blocks.
On division "B," pave with Eastern granite blocks.
On division "C," pave with best sheet asphalt.
On division "D," pave with granite-quartzite selenite macadam.
On division "E," pave with best paving brick.
On division "F," pave with best cedar blocks.

Explanatory of location: The street to be used for tests should be

such as will lie in and from the business section of the city, hence, permitting the arrangement by which granite-quartzite blocks, being the hardest of all material, would get the most exposure. The top of the foundation would be everywhere the same, but, as in the case of asphalt, etc., they would gladly put on a sub-top, to adjust the thin wearing coat to general conditions.

To meet actual expenses only, let the committee select a division where the city has laid an assessment. Secure a five-year guarantee for repairs or repaving, each company to have its own methods subject to the specifications and the orders of the City Engineer of Indianapolis. I cannot conceive of a more positive good than such a test would insure.

CHICAGO, January 22d, 1891. W. L. S. BAYLEY,
Civil Engineer.

Mr. Calkins' suggested standard of quality is in line with the foregoing, and I do not wish to be understood as in any way attempting to controvert the practical utility of the standards which he has proposed, although I wish to cite to him the Providence tests by way of indicating that his proposed standard of abrasion will be somewhat difficult to attain. My points are: (1) that we need more information; and (2), inasmuch as the municipal boards have thus far seen fit in only a few cases to assist in furnishing it, the magnitude of the paving interests is such as to justify the manufacturers themselves in furnishing by concerted action what is now lacking. The expense, while considerable, would not be excessive, and if the results of a thorough series of scientific tests essentially verify the claims which have been made, the benefits to the brick paving interests will be almost incalculable.

In reference to the specification for quality which Mr. Calkins cites, it may be remarked that if we had a standard of durability and fitness already established with approved methods of ascertaining the value of any given material with reference to the standard fully worked out, then the proposed clause would be a clear improvement on the ordinary specification as quoted by him. As the matter stands, however, there is at the present time absolutely no generally recognized standard of quality except the perfectly general one derived from actual experience in use. The clause which Mr. Calkins quotes with approbation, may be fairly interpreted therefore as admitting to use, any and all material of which it could be claimed that it had been burned specially for street paving purposes, excepting, of course, such brick as failed to conform to the specification for square edges, straightness, freedom from cracks, etc. The general adoption of the clause in question would, therefore, it seems to me, in the absence of a standard, lead to more controversy as to admissible quality than takes place under the ordinary clause. Mr. Calkins states that the author of the proposed substitute clause is to him unknown. The present writer noted it nearly two years ago in specifications for brick pavements, prepared by Mr. John L. Culley and published

at page 219, Vol. XXIII of *Engineering News* (issue of March 8th, 1890); but whether or not Mr. Culley is the original author, I am unable to say. In thus doubting the utility of the clause in question, I do not overlook the fact that the use of tests for paving material is extending so rapidly as to mark a distinct advance toward more scientific methods in paving engineering. For such advance we are, I think, largely indebted, so far as this country is concerned, to the growth of the brick paving industry.

The few tests recorded in the last two or three years have shown such considerable variations in quality of material from different localities as to markedly emphasize the importance of a standard, probably the best thus far made.*

The need of a standard for tests is shown by those given below:

At Kansas City Mr. Butts tested for compression, absorption and abrasion, while in the Providence series Mr. Shedd made no tests whatever for compression, but tested for absorption, abrasion and penetration by oil. At Kansas City the absorption test was made by breaking the brick in two and immersing in water for forty-eight hours; at Providence the whole bricks were immersed for twenty-four hours Again at Kansas City the abrasion test merely included placing the bricks in a foundry rattler with a lot of small castings and running the rattler at the rate of about 100 revolutions per minute for fifteen minutes; at Providence, on the contrary, the bricks were run in a rattler for six hours and the loss of weight taken at the end of each hour.

In order to make a specification, avoiding indefiniteness and at the same time furnishing the engineer a certain method of procedure, under any and all circumstances, two courses are open, namely: (1) to either reserve the right to make, before awarding the contract, any test of submitted material that the engineer may see fit to make, and award the contract in accordance with the results of such tests; or (2) prescribe in the specification the definite tests to which the material will be subjected, with such reservations as to time and place as the exigencies of each particular place seem to demand. In Cleveland, "The City Engineer reserves the right after the bids are received and before the awarding of the contract to any bidder, to make such tests of the sample bricks deposited in the Engineer's office, as said Engineer shall recommend or deem necessary to determine the durability and fitness of the material proposed to be furnished by such bidder as shown by his samples, and reserves the right to hold the bid not exceeding two weeks for such purpose, and any brick not fulfilling the requirements of the specifications or that may be deemed unfit for paving purposes, as shown by such tests, will be rejected and the bid considered as not in conformity with said specification."

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* *Engineering News*, April 11th and September 26th, 1891; and *Engineering and Building Record*, May 2d and September 26th, 1891.

I submit for comment and criticism the following clause:

The paving material shall consist of the best quality of sound, hard burned merchantable brick, manufactured with special reference to use for street pavements; all the brick furnished will be subject to test for absorption, abrasion and crushing. Each bid shall be accompanied by at least six bricks of the quality which it is proposed to use in the work, all plainly stamped with the bidder's name, and before the award of the contract the said tests shall be made upon the sample brick so furnished. The results of these preliminary tests upon the samples from the bidder whose proposition is accepted will be considered the standard of comparison during the progress of the work. Any one or all of the tests may be applied in the discretion of the Engineer, at any time while the work is in progress, and whenever, as the result of such tests, the said Engineer shall conclude that material not contemplated by the contract is either being used or proposed to be used, all of the same which he may designate shall be immediately removed, etc.

The following is the quality clause of the specifications for brick pavements now in use in Rochester:

"All brick used must be of the best quality manufactured by....., being uniform in size, clear-ringing, whole, hard-burned, burned entirely through, tough, free from brittleness and cracks, and with true and smooth faces."

The brick pavements, as constructed in Rochester, are provided with concrete foundations 6 inches in thickness, the upper surface of which is made smooth, and parallel with the surface of the pavement to be laid. Upon the concrete base, clean, sharp sand, free from small pebbles, is evenly spread of such thickness, that, after the pavement has been laid and thoroughly rammed, the compacted sand will be 1 inch in depth. Before laying the concrete the sand is thoroughly compacted with a 5-ton roller. The evenness of the sand is insured by a template formed to the prescribed crown of the street, which is laid across from curb to curb and drawn forward by hand.

The bricks are set on edge, vertical, and to line in courses at right angles to the curbs; and after being placed in position they are settled to place by ramming with heavy mauls used on 2-inch plank. After the ramming the joints are completely filled with an asphalt paving cement, used hot, and the joints repaved until completely filled. In good work from 2¼ to 2½ gallons of the cement are used per square yard, and at a cost, including labor, of about thirty cents for that area.

I offer, in conclusion, the following views:

(1.) For light traffic a brick pavement may be made at low cost in places where the material is close at hand, which will fairly meet the conditions for a number of years.

(2.) For medium traffic the making of the concrete foundation which appears necessary, in order to secure stability, increases the cost so

much that no special gain can be predicated, provided other approved material is available.

(3.) For heavy traffic we as yet lack the data to justify the use of brick for paving.

(4.) In localities where no other durable paving material is available the use of brick is to be commended, and the perfecting of the material and methods of use have been of value to extensive regions, where this condition largely exists.

(5.) It is not fair to conclude that what is best suited to one locality is necessarily the indispensable condition for successful and economical paving in another. The fitness of the material for the special locality ought to chiefly govern the decision as an engineering question.

(6.) We need greatly a definite standard of quality in which shall be clearly defined by several different tests the relative efficiency of a number of the leading paving materials, in such manner as to indicate the approximate durability of a given material under given conditions of use.

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ELECTRIC LIGHTING AT TOPEKA, KANSAS.

By LEWIS KINGMAN, M. Am. Soc. C. E.

WITH DISCUSSION.

There are few wants more necessary in a well regulated community than light. After securing a generous supply of pure fresh air, good wholesome water, clean streets and surroundings well drained, we need light by night as well as by day. During the last few years many of our smaller cities, seeing the improvement made in larger places, have secured electric light plants. Some, from a spirit of rivalry, have gone into these enterprises blindly, without counting the cost or carefully considering the questions involved. The strong, convincing argument in favor of the arc lamps is the great concentration of light in one lamp. But the light received is as the square of the distance lighted, a fact that is often overlooked.

There are many inquiries constantly being made as to the cost and operation of an established plant. One of the first asked is, does the city own its plant? A question in municipal economy which should re-

ceive more attention. That a city should be free to supply its own needs and that of its citizens at cost, without the presence of middlemen to overcharge or discriminate, would seem self-evident.

The next important question is the cost. In reply to such questions, the author has prepared a tabulated statement, taken from the reports of the superintendents, which covers the operation of the plant for the last twenty-six months, giving the number of nights and hours run each month and the principal elements of cost, together with the cost of fuel for each horse-power for one night and hour.

The plant belongs to the City of Topeka; it was contracted for in February, 1888, and furnished by the Jenney Electric Company, of Indianapolis. There are one hundred and eighty-four double carbon arc lamps, three boilers 16 feet long, 54 inches in diameter, with forty-five flues 4 inches in diameter; three Ball engines of 75 horse-power with 80 pounds of steam pressure, intended to run two hundred and fifty revolutions a minute, six dynamos of thirty arc lamp power, connected with six circuits which together have 24.72 miles of line and 33.5 miles of wire; the line is suspended upon 30-foot cedar poles, and the lamps are suspended at the center of the street intersections between two 40-foot poles. Soon after starting it was found necessary to use more than 80 pounds of steam pressure, and in doing this the capacity of the boilers was found inadequate, except with the best bituminous lump coal. From the tests and experience of a superintendent who was in charge of the plant about one year, it was found that the three engines had to work up to 235 horse-power to keep the lamps burning steadily. The exact actual horse-power record has not been kept during all this time.

The accompanying table shows some irregularities. Owing to lack of boiler capacity the plant has to be shut down two nights each month to clean them. This is usually done on moonlight nights, but sometimes it is cloudy and the moon obscured, much to the annoyance of our people. In October, 1891, the plant was shut down for fifteen days to reset the boilers.

The monthly statements of the cost of coal is for coal received and paid for during the month; this comes by the carload, which is ordered as needed, and very little is kept in stock at any time. Owing to the lack of capacity of the boilers, the poorer and cheaper coal, such as is used by other electrical plants in the city, cannot be burned.

An expert tested some of our lamps without the knowledge of the

superintendent and operators, and found as an average of seventeen lamps in different parts of the city a pressure of 23.15 volts, a current of 19.0 ampères, and an electromotive force of 439.85 watts. The manufacturers of electrical plants using arc lamps have fixed an arbitrary standard of their own for candle-power. Six of the largest companies allow from 432 to 480 watts for a 2 000-candle lamp; the average of these is 450 watts to the lamp or 4.44 candles to the watt. The author has endeavored to find some reason for their assumption, but knows of none except that they overrate their lamps for what they can gain by imposing upon their customers. The best authority that he can find on the subject is Gordon Wigan, A. M., whose work was printed in 1884 by Cassel & Co., New York, and who makes one watt equivalent to 1.63 candles, and cites a test of candle-power at the Paris Electrical Exposition of 1881, when the Brush lamp was tested and shown to be 741 candle-power. By the American manufacturers' average arbitrary standard, the seventeen lamps tested averaged 1 953 candle-power, allowing 4.44 candles to the watt; but taking Wigan's and the European practice our lamps are only 717 candle-power, allowing 1.63 candles to the watt. This is a great difference, when it is considered that we use the same English standard candles as are used in Europe and elsewhere, for our standard in this country.

The location of the electric lamps in our city has been a subject of much criticism, with one lamp at every other street intersection; the lamps are about 1 100 feet apart one way and 800 feet the other; the intervening intersections are not well lighted, which is hardly fair to the people living there. With one lamp at every intersection the light would be of much more value, even though the intensity was only one-half of the light of the present lamps.

We have in addition to our electric lamps 222 vapor lamps furnished and lighted by contract at $1.75 per month. These are located in the outlying districts. People complain because they are so insignificant as compared with the arc lamps, and when one compares a vapor lamp of 10 candle power with a 700 candle power lamp, it is not much to be wondered at that some of these districts should complain through their representatives. The City of Topeka is spending $21 260 a year for lighting its streets, and yet people are not satisfied. About one-half of those inside of the electric light district feel that an injustice has been done them, and all of the people outside of this district seem to think

Cost of Operating the Topeka Electric Light

The plant consists of a building and lot with a railroad switch in the rear; there are three arc dynamos of 30 lamp-power each. There are six circuits, with 24.72 miles of line and 33.5 at the center of the street intersections between two 40-foot poles, one lamp to every other 184 arc lamps rated at 2 000 candle-power. An average test at the lamps showed a pressure of

Year and Month.	Nights Run During Month.	Hours Run During Month.	Average Number of Hours Run.	Coal.		Cost of Coal per Horse-Power.		Cost of Carbons.
				Tons.	Cost.	Per Night.	Per Hour.	
						Cents.	Cents.	
1889. Nov.	28	340.03	12.14	236.0	$566 40	8.60	0.71	$119 07
Dec.	29	373.47	12.88	261.0	626 40	9.19	0.71	142 40
1890. Jan.	29	357.40	12.32	222.0	532 80	7.82	0.63	142 40
Feb.	26	298.73	11.49	216.9	520 56	8.52	0.74	123 00
March	27	274.83	10.18	194.85	459 40	7.24	0.71	123 00
April	30	265.42	8.84	190.0	456 00	6.47	0.73	109 67
May	28	171.92	6.14	156.0	374 40	5.69	0.93	70 27
June	27	132.91	4.92	76.0	182 40	2.87	0.58	50 90
July	28	146.34	5.22	110.4	283 86	4.31	0.82	50 00
August	28	182.50	6.51	144.0	345 60	5.25	0.80	70 27
Sept.	27	211.69	7.87	154.3	403 66	6.36	0.81	81 98
Oct.	25	204.04	8.16	110.0	361 11	6.15	0.75	79 56
Nov.	24	206.00	8.58	126.35	385 37	6.83	0.80	74 02
Dec.	25	198.25	7.93	123.4	373 70	6.36	0.80	83 65
1891. Jan.	24	189.17	7.88	122.65	374 08	6.63	0.84	71 70
Feb.	21	157.50	7.50	83.75	249 18	5.05	0.67	65 72
March	23	158.50	6.89	102.80	302 73	5.60	0.81	71 70
April	21	141.83	6.75	109.0	317 42	6.43	0.95	64 80
May	23	127.05	5.52	101.0	294 99	5.46	0.99	60 00
June	23	118.08	5.13	86.8	264 74	4.89	0.95	55 20
July	27	138.75	5.14	75.13	230 73	3.63	0.71	55 80
August	28	172.05	6.14	90.10	274 80	4.17	0.68	72 00
Sept.	30	251.05	8.37	108.95	331 55	4.70	0.56	72 00
Oct.	16	140.75	8.79	106.00	323 30	8.60	0.98	60 00
Nov.	28	244.41	8.73	136.45	395 70	6.01	0.69	96 00
Dec.	27	227.50	8.43	143.20	415 28	6.54	0.77	90 00
Totals	672	5 430.17	Av. 8.08	3 587.03	$9 646 16	Av. 6.11	Av. 0.76	$2 146 11
Per cent. of total expense					26.04			5.79

Plant, Owned and Run by the City of Topeka.

boilers and three engines, worked up to 235 horse-power; there are six Jenney, Indianapolis miles of wire. The line poles are 30 feet long, of which there are 943. The lamps are suspended intersection, making them 1 100 feet apart one way and 800 feet the other. Together there are 23.15 volts and a current of 19.0 ampères, 439.85 watts, or 1 953 nominal candle-power.

Cost of Globes.	Cost of Oil and Waste.	Cost of Repairs.	Expenses Insurance Telephone.	Pay-roll of Superintendent and Labor.	Interest on Cost of Plant, at 6 per cent	Total Cost Entire Expense, per Month.	Cost per Lamp per Month.	Cost per Lamp per 100 Hours.
$13 50	$22 15	$12 15	$32 88	$483 32	$277 24	$1 517 71	$8 25	$2 43
8 25	27 27	133 74	29 58	531 00	277 24	1 775 88	9 65	2 59
18 75	26 93	167 97	30 68	497 50	277 24	1 694 27	9 21	2 58
9 00	23 31	154 89	28 58	496 25	277 24	1 632 83	8 88	2 97
13 00	23 45	180 13	29 58	498 00	277 24	1 603 80	8 71	3 17
13 38	25 29	90 21	32 59	509 75	277 24	1 514 13	8 23	3 11
8 17	24 06	27 47	29 38	508 33	277 24	1 319 32	7 17	4 17
3 50	32 25	94 07	31 83	516 50	277 24	1 188 69	6 46	4 86
3 50	19 60	100 78	37 93	523 38	277 24	1 296 29	7 04	4 82
2 50	21 36	57 90	32 48	515 75	277 24	1 323 10	7 19	3 94
5 00	25 32	48 95	32 73	516 50	277 24	1 391 38	7 56	3 56
5 00	22 10	64 72	34 48	467 75	277 24	1 311 96	7 13	3 50
9 00	22 00	79 78	49 03	523 41	277 24	1 419 85	7 72	3 75
3 50	15 61	86 11	31 78	525 00	277 24	1 396 59	7 59	3 83
6 00	19 89	100 29	38 08	530 25	277 24	1 417 53	7 70	4 07
3 50	17 30	195 94	33 26	529 50	277 24	1 371 64	7 46	4 75
2 50	13 83	102 11	36 73	528 98	277 24	1 335 82	7 26	4 60
3 00	13 98	41 35	37 36	525 75	277 24	1 280 90	6 96	4 90
3 00	10 30	56 29	45 56	525 00	277 24	1 272 78	6 92	5 45
4 00	9 92	56 04	47 46	525 00	277 24	1 229 60	6 68	5 66
4 00	10 36	39 80	40 91	525 00	277 24	1 183 84	6 43	4 63
2 00	14 62	67 57	33 31	525 00	277 24	1 266 54	6 88	4 00
3 00	20 70	171 95	35 61	525 00	277 24	1 437 05	7 81	3 11
2 00	10 85	730 69	35 16	510 00	277 24	1 949 24	10 59	7 51
6 00	19 50	110 59	35 86	533 10	277 24	1 477 99	8 03	3 29
4 00	12 40	74 29	33 01	525 97	277 24	1 432 19	7 78	3 43
$159 05	$504 35	$3 045 78	$905 84	$13 420 99	$7 208 24	$37 036 52	Av. $7 74	Av. $3 71
0.43	1.36	8.23	2.45	36.24	19.46	100.00		

Cost of lots and buildings..... $ 8 559 33
" " plant, poles and wire..... 46 888 65

Total cost..... $55 447 98

they ought to have as good light as the electric lamps furnish, as they are assessed in the same proportion as those who have them. What we need is a system of lamps at every street intersection, with one circuit covering the business portion of the city on which the lamps shall have an intensity of 1 000 actual candle-power. Then with circuits covering the residence and outlying districts on which the lamps shall have an intensity of 200 candle-power. One objection, perhaps, to this would be the large additional number of lamps to clean, adjust and take care of; another would be the long distance for the transmission of the electric current and consequent loss or leakage.

The present arc lamps are good, perhaps, perfect in themselves, yet the cost is so great that a city occupying a large territory cannot expect to light all and do equal justice to its citizens.

The Edison lamps have not the candle-power suitable for street lighting, but it would seem to the author that a system between the two would be more suitable for many of the growing cities in our country.

The cleaning of the arc lamps and the globes is a large item of expense and is seldom done perfectly. Fifteen per cent. of light is absorbed by a good clean globe, 70 per cent. by an opal globe, and about the same amount by a dirty globe. The rods of an arc lamp must be kept clean or it will fail to burn, and the cleaner is at once reminded of his duty; but he can allow the globes to become obscured so that from 50 to 70 per cent. of the light is absorbed without any serious complaints from an average citizen. Municipal engineers are largely interested in the question of light. We should try and secure its proper diffusion, that equal justice may be done to all. An engineer should first know what his city needs, and then be able to advise, and prevent a fluent agent of a strong illuminating company from selling an extravagant plant, poorly adapted to the wants of its people.

DISCUSSION.

JOHN W. HILL, M. Am. Soc. C. E.—For public street lighting, arc lamps with clear glass globes, of less than 2 000 (so-called) candle power, at all street intersections, with weaker lamps midway of blocks, will probably give the best satisfaction in point of cost and illumination, to the people in the district lighted. The total lighting power of almost any town or village system of electric lighting will be sufficient to fur-

nish a satisfactory illumination if this be divided so as to give a light at each street intersection, and in long blocks at least one lamp midway of intersections.

While incandescent lamps of 100 or less candle power can be easily and rapidly measured for illuminating power with the photometer, it is much less convenient to measure the illuminating power of arc lamps, and as a consequence there is much guessing at the capacity of such. If it were not for the great cost, I believe incandescent lamps of 100 candle power properly distributed would give a more satisfactory illumination of public streets and highways than arc lamps; with this objection, however, that the illuminating power of arc lamps with clean carbons and globes is a practically constant quantity, while incandescent lights are steadily on the wane, and our 100 candle power light, which, when new, may give 150 candle power effect, at the end of several weeks may have been worked down to 75 or 80 candle power, while the cost of maintaining the lamp will be the same at the lower as at the higher illuminating power.

From some experiments which I made several years ago with an isolated Edison Incandescent Electric Lighting plant, it appeared that the cost of a sixteen candle power light per hour is about three-fourths of a cent, or for 100 candle power lamps, 4½ cents per hour, and with an average illumination of twelve hours per night, the cost of each 100 candle power lamp would be $197 per year, and assuming two incandescent lamps for each 2 000 candle power arc lamp in the Topeka lighting circuit the annual cost would be $70 920, as against an average cost of $93 per lamp per year, or $16 718 per year for the whole number of one hundred and eighty lamps now in use. But the present system furnishes a total illumination of $717 \times 180 = 129\,060$ candle power, while the three hundred and sixty incandescent lamps would furnish only 36 000 candle power, or while furnishing but 28 per cent. of illuminating effect, the incandescent system would cost nearly four and one-fourth times as much as the arc lighting system; or for the same total illuminating effect the cost of the incandescent system would be fifteen times as much as the cost by the present arc system of lighting.

It is this great difference of cost which discourages the use of the incandescent system for street lighting, although, where it can be afforded, the latter will give the most satisfactory results in public highways by bringing the lamps nearer together and closer to the surfaces to be illuminated.

E. E. Magovern, Jun. M. Am. Soc. C. E.—Mr. Kingman's paper, in its introduction, raises the interesting question, applicable to all kinds of municipal enterprise, should the city own its plant? It is difficult to appreciate how any intelligent community, exceptional cases aside, can come to any different conclusion, for electric light plants, at least, than that arrived at in the paper in question. The possible exceptional cases being instances where it would be cheaper for a city to contract tem-

porarily for its electric lighting rather than bond the municipality in a tight money market at exceptionally high rates of interest. The arguments of those opposed to the almost axiomatic answer above indicated are found in a paper by Mr. M. J. Francisco, read before the National Electric Association in August, 1889, and may be recapitulated thus:

First.—That as the state has chartered a company for electric lighting, the city or town, as a composite unit of the State, infringes on the vested rights of the chartered company in providing its own plant.

Second.—That the cost, if correctly stated, to the municipality, is far in excess of the cost when supplied by a corporation.

Third.—If a municipality can sell electricity cheaper than private companies, why should it not manage all other industries and trades in the community?

Fourth.—That a municipality cannot afford to take the same risks of development in apparatus and in economical management. The writer's reply to these arguments is:

1. That a charter cannot be legally granted, giving exclusive rights to a corporation over individuals or municipalities.

2. Though Mr. Francisco, in a subsequent article (*Electrical Engineer*, Vol. XI, No. 154, page 440), criticises the list submitted below as being "the familiar list, which has proved a veritable will-o'-the-wisp, leading its votaries deeper and deeper into the labyrinths of political necromancy," and though the criticism made in the case of Chicago municipal plants is, to the writer's mind, well founded; yet the preponderance of evidence is clearly in favor of municipal management, and until Mr. Francisco is able to show that more conjuration of accounts occurs with municipal than with private plants, the writer submits that a true basis for judgment exists in the much maligned list (*Engineering Record*, Vol. XXIV, No. 5, page 78).

The following is a list of cities supplied with light by private corporations:

Name of City.	Schedule.	Number of lights.	Cost of light per night, cents.	Candle power.
Kansas City, Mo.	All night.	114	55	2 000
Atlanta, Ga.	"	596	53½	2 000
Baltimore, Md.	"	607	40	2 000
Binghamton, N. Y.	"	123	36	2 000
Birmingham, Ala.	"	100	33	2 000
Buffalo, N. Y.	"	1 296	40	2 000
Cleveland, O.	"	100	38	2 000
Denver, Col.	"	1 297	53	2 000
Duluth, Minn.	"	100	35	2 000
Jackson, Mich.	"	210	24	2 000
Lowell, Mass.	"	180	50	2 000
Memphis, Tenn.	"	100	50	2 000
New Bedford, Mass.	"	90	40	2 000
New Haven, Conn.	"	.....	48	3 000
Richmond, Va.	"	134	40	1 200
St. Louis, Mo.	"	1 587	20½	2 000
Sedalia, Mo.	Moonlight—out.	91	24½	2 000
Springfield, Ill.	"	110	38½	2 000
Troy, N. Y.	All night.	297	39½	2 000
Wichita, Kansas.	"	90	30	2 000

Similarly, the following is a list of cities that own their electric light plants:

Name of City.	Schedule.	Number of lights.	Cost of light per night, cents.	Candle power.
Bay City, Mich	All night.	134	16⅔	2 000
Bloomington, Ill	"	220	20	2 000
Chicago, Ill	"	520	10	2 000
Hannibal, Mo	"	96	14½	2 000
Lewiston, Me	"	96	11⅔	2 000
Little Rock, Ark	"	110	13½	2 000
Madison, Ind	"	85	13½	2 000
St. Joseph, Mo	"	208	14½	2 000

3. That it is a well known principle that we cannot logically generalize without abstracting, but that we may perform abstraction without generalization.

4. That the material and practical advances in economy in electric lighting are so slow, that the municipal plant, being less given to experimentation, can well afford to adopt, as they arise, the successful experiments made by private corporations.

Reverting to the table of costs of operating in Mr. Kingman's paper, it is readily found that the average cost per night's run per month is 25.8, and the average per night per light is 30 cents; an excellent result when compared with the figures given in the first table, of cities supplied with light by private corporations, when plants of the corresponding size and the location of the plant are considered. Moreover, the efficiency of the plant, considering the length of the circuit, should be thoroughly satisfactory, as the following calculation will show: One hundred and eighty-four lamps at 439.85 watts per hour equals 80 932.5 watts or 108.5 electrical horse-power (E. H. P.) at the lamp, an efficiency of over 46 per cent. The losses, 54 per cent., include engine friction, transmission to dynamo, dynamo losses, losses in wire transmission and losses at the lamp. The writer has seen higher figures of efficiency, but none as high where the circuit is as long and the lights as few.

The question of electric light standards has been happily presented by Mr. Kingman and is a subject worthy of attention. Some years since, the writer, while engaged in an engine test, in which a dynamo had been provided to furnish the resistance, was requested by the makers of the dynamo to certify to the number of sixteen candle power lamps per indicated horse-power per hour; the photometer provided, though of standard make, proved so unsatisfactory that no certificate could be furnished. While the illuminating power of the electric light was nearly constant, so long as the volt-ampères were constant, it was found that in a thirty-minute run the illuminating power of the standard candle varied nearly 20 per cent. Again, a committee appointed some

years ago by the British Board of Trade, to report upon photometric standards, found that standard candles from different makers varied so greatly that one flame would in some cases give 16, in others 18 candle power. Beside this, it was found that a candle varied from day to day, and a variation was noted in the same candle of 12 per cent. in two minutes. It is, therefore, of extreme importance to the engineer that some more stable standard be fixed; several of these have been proposed. One, Harcourt's, is the burning of a mixture of 7 volumes of Pentane mixed with 20 volumes of air and the resultant combination burned at the rate of half a cubic foot per hour in a burner of special design so as to produce a flame of definite height. The objection to this standard is, to the writer's mind, in the inherent variable character of Pentane, to wit ("Fowne's Chemistry," edition 1878, page 499):

Normal Pentane or Ethyl-Propyl, C_2H_5—C_3H_7. Rankine has shown ("Steam Engine," etc., Section 224, page 271), "that the total heat of any compound of hydrogen and carbon is nearly the sum of the quantities of heat which the hydrogen and carbon contained in it would produce by their combustion if burned separately."

This would give: Pentane, modification, C_2H_5.

$C \times 2 \times 12 = 24$
$H \times 5 \times 1 = 5$

Molecular weight = 29 Heat units.

Hence $\frac{24}{29}$ pounds of carbon burned gives, $\frac{24}{29} \times 14\,500 =$ 12 000
and $\frac{5}{29}$ pounds of hydrogen burned gives $\frac{5}{29} \times 62\,032 =$ 10 695

giving for the total heat per pound of Pentane, modification, $C_2H_5 =$ 22 695

And, Pentane, modification, C_3H_7.

$C \times 3 \times 12 = 36$
$H \times 7 \times 1 = 7$

Molecular weight = 43

Hence $\frac{36}{43}$ pounds of carbon burned gives $\frac{36}{43} \times 14\,500 =$ 12 139
and $\frac{7}{43}$ pounds of hydrogen burned gives $\frac{7}{43} \times 62\,032 =$ 10 098

giving for the total heat of Pentane, modification, $C_3H_7 =$ ..22 237

The resultant mechanical energy is:

For C_2H_5, 22 695 × 772 =.....17 520 540 foot-pounds.
For C_3H_7, 22 237 × 772 =.....17 166 964 " "

Prof. Julius Thomsen (*Philosophical Magazine*, 1865, Vol. 30, page 246), has shown that the mechanical equivalent of light is about 12.28 foot-pounds per minute, or 736.8 foot-pounds per hour per candle power; hence the candle power per pound is:

C_2H_5, 17 520 540 ÷ 736.8 =.....23 779 candles.
C_3H_7, 17 166 964 ÷ 736.8 =.....23 299 "

Accepting Regnault's determination of the weight of hydrogen, one litre at standard pressure and temperature weighs 0.0896 grams, and the gaseous densities being as one-half the molecular weights, we have, reverting to English measures, 1 cubic foot of C_2H_5 weighs .08107, and 1 cubic foot of C_3H_7 weighs .1202 pounds.

Taking the combination as above, viz.: 7 parts Pentane to 20 parts by volume of air, we have for the actual weight of Pentane burned per candle power per hour:

C_2H_5..... .010509 pounds.
C_3H_7..... .015581 "

and taking these proportions of the candle power of 1 pound of the combination, we have seven volumes Pentane, mixed with twenty volumes of air, and burned at the rate of five-tenths of a cubic foot per hour, equivalent to:

Modification: $C_2H_5 = 23\ 779 \times .010509 = \ldots 250$ candles.
Modification: $C_3H_7 = 23\ 299 \times .015581 = \ldots 363$ "

It is evident that this standard, varying as just shown, is as objectionable as that of a sperm candle, six to the pound and burning at the rate of 120 grains per hour. Other proposed standards will, when analyzed as above, be found equally objectionable. What is needed is an exact fixing of the mechanical equivalent of light in foot-pounds per hour or minute, and the requiring, by the engineer, of a maintenance at the lamp of the equivalent volt-ampères. The expression "exact fixing of the mechanical equivalent of light" is made advisedly, as another experimenter, Mr. M. G. Farmer (*American Journal of Science and Arts*, 1866, Vol. 41, page 215) gives such mechanical equivalent as 10.1 foot-pounds per minute. The writer presumes the reason for the assumption questioned by Mr. Kingman can be discovered thus: 33 000 foot-pounds per minute = 746 watts per minute, or 1 watt = 44.23 foot-pounds per minute; and as per Farmer's determination 10.1 foot-pounds per minute = 1 candle power; hence $44.23 \div 10.1 = 4.37$ candles = 1 watt. The figure quoted by Mr. Kingman, the origin of which was unknown to him, 4.44, is a close approximation to this.

The question of the location of the lamps brings to remembrance that a recent number of a well known technical journal contains the following remarkable, unqualified statement: "The proper height at which electric arc lights should be placed is 0.7 of the radius of the area to be illuminated." If the lights were thus placed in Topeka the resultant illumination would indeed be slight. The writer, in conclusion, believes the paper of Mr. Kingman to be exceptionally valuable in that it shows what may be done by competent engineering supervision as opposed to the happy-go lucky method of trusting to the word of such an agent as described, whose pay is in direct ratio to the sales made, and independent of the result of such sales.

LEWIS KINGMAN, M. Am. Soc. C. E.—Mr. Magovern quotes from the *Engineering Record*, Vol. 24, No. 5, page 78, naming twenty cities supplied with arc lamps by private corporations and eight cities that own their own plants. These statements differ so materially that one is led to believe the facts are not correctly stated. Take Chicago, for instance, 10 cents per lamp all night would be $36.50 per year per lamp. On page 253, Vol. 13, No. 201 of the *Electrical Engineer* the editor states the cost of each arc lamp as being $136.96 per year or 37½ cents per night.

The City Clerk of Hannibal, Mo., informs me, April 15th, 1892, that they have fifty-four public arc lamps and forty-four private lamps, which cost the city $6,985.43 to operate last year, or $71.28 per lamp per year; this would be 19½ cents per lamp per night. The city collects $4,324.70 for the forty-four private lamps furnished, but this does not affect the cost. A much more extended comparative statement was printed by the *Water and Gas Review*, Vol. 2, No. 8, pages 7 to 10 inclusive, compiled by Charles Baillairge, City Engineer of Quebec, in a list of ninety cities; but two are run at less than $90 per lamp per year on an all-night basis, and only eleven out of the ninety are run for less than $100 per lamp per year on the same basis.

Mr. J. P. BARRETT, of Chicago, writes: Our lights are now costing about $100 per annum, not including interest, taxes or depreciation. Our lamps are 2 000 candle-power (nominal), 601 being high tension and 392 low tension; operated from four power stations, with the circuits all underground. The lamps are lighted from dusk till daylight every night in the year, the average being ten hours and forty-five minutes each night. The stations were designed to have capacity for 1 000 arc lamps of 2 000 candle-power each.